WAVELENGTH DIVISION MULTIPLEXED TRANSMISSION OF SPREAD SPECTRUM MODULATED SPEECH SIGNAL THROUGH FIBER OPTIC LINK

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CERTIFICATE

This is to certify that the work on WAVELENGTH DIVISION MULTIPLEXED TRANSMISSION OF SPREAD SPECTRUM MODULATED SPEECH SIGNAL THROUGH FIBER OPTIC LINK has been carried out by Goutam Deb under our supervision and this has not been submitted elsewhere for a degree.

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ABSTRACT

Wavelength division multiplexing (WDM) scheme is used to mprove the capacity of a fiber-optic communication link. ptical signals at different wavelengths are multiplexed toge-her using this technique. At the receiving end they can gain be separated according to their wavelengths using a WDM lemultiplexer.

Wide bandwidth capability of optical fibers make them very much suitable to transmit large band signals like spread - spectrum modulated (SSM) carrier. Combination of these two techniques can give rise to some significant advantages in a communication network or telemetric systems where different users at different places are sharing the same channel.

In the present work spread-spectrum multiple access system has been implemented and it has been tested for two asynchronous users. A WDM multiplexer adds the local signal with the incoming signal at the tapping point. Two LED's being used as sources operate at 820 nm and 900 nm wavelengths respectively. The WDM multiplexer has been realised using a beam splitter and collimating and focussing lenses. A single multimode fiber is being used as the optical channel.

One source sends a digitized voice signal modulated by SSM signal in the link whereas the other source sends a maximal length. PN sequence asynchronously at the same data rate. At the receiving end the SSM receiver circuit recovers the digitized voice signal from the composite signal received. Finally this signal is fed to the source decoder circuit to get back the original voice signal. Performance of the system has been evaluated by measuring bit-error rate (BER) and the results confirm its reliable performance as a communication data link.

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CHAPTER 1

INTRODUCTION

1.1 INTRODUCTION TO OPTIC-FIBER AS A COMMUNICATION CHANNEL:

In recent years the use of optical fiber as a communication channel has drawn tremendous attention. The reasons for its popularity are the following important advantages it offers over co-axial cable [1,2].

i) Low loss : It leads to larger repeater spacing; even upto 100 km

ii) Large bandwidth

iii) Smaller size and weight : Therefore installation of cable becomes easy.

iv) Immunity from electromagnetic interference (EMI) and electromagnetic pulses (EMP)

v) Cost effective for large data-rate

vi) Security : No radiation hazard.

Fiber optic communication is specially attractive for the digital systems for the large data rate it can handle. Status of a few fiber-optic digital communication systems which have undergone field trial are given below.

Year Impleme-nted	Name	Installed by	Data rate	Sources used	Detector used	Max. repeater spacing	Total length	Error rate
1975	Atlanta Experiment[3]	Bell Laboratories.	44.7 Mb/s	Lasers	APD's	10.9 km	-	10^{-6}
1976	British Telecom. Research[4]	British Telecom.	8 Mb/s	Lasers	APD	No Rep.	8 km	
	Spanish National Railway[5]	ITT	2 Mb/s	Lasers	APD	No Rep.	13 km	
1978	Joplin CATV trunk[4]	Cablecom - General	20 Mb/s	LED	APD	3 km	6 km	
	Victoria-Vrraza[5] route, Mexico	ITT	34 Mb/s	Lasers	APD	No Rep.	7.6 km	10^{-10}
1978	Transmitter System[6] Demonstration	Paper presented by Balwin and EPPES	2.3 Mb/s	Lasers	APD	10 km	32 Km	10^{-9}
1981	ECL and Atsugi[4], Japan	ECL Musashino	400 Mb/s	Lasers	APD	4 km	80 km	

Even an excellent communication channel like fiber-optics has certain limitations. Some of which are

i) Although fiber optic cable itself is inexpensive, opto-electric and electro-optic transducers and some other opto-electronic components are very costly.

ii) There has been little standardization of components and devices so far. Components and devices from different manufacturers have different specifications.

iii) Design of the pre-amplifier in the receiver front end is much more demanding in this case because of the very weak output available from the receiver opto-electric transducer [7].

iv) Splicing two fiber ends, attaching a connector etc. are elaborate and difficult. In coaxial cable similar operations are much easier.

1.2 SPREAD SPECTRUM SIGNALLING:

Due to the large bandwidth available in optical fiber links one can successfully employ a robust modulation technique like spread-spectrum modulation (SSM). In spread - spectrum modulation one of the methods used is to modulate the incoming data by a pseudo-noise (PN) sequence. The PN sequence length should be equal to the data symbol interval

and they are modulo-2 added in case of digital signals. For spread-spectrum multiple access system (SSMA), each user is allotted a distinct PN sequence and data from each user is modulated by the respective PN sequence. At the receiving end respective users decode the data using an exact replica of the modulating PN sequence. To reduce the interference between different users sequences having good cross-correlation property like Gold and Kasami sequences are used. Cross-correlation values of these codes show a decline as the length of the PN sequence increases. Hence to achieve near optimal performance one has to use a large sequence length. This, however, demands greater channel bandwidth. If the channel is capable of handling the bandwidth required to send a spread-spectrum modulated signal, this technique can offer the following important advantages:

i) Asynchronous Multiplexing: Here different users can send the data through the link asynchronously. Transmission by different users may be at different data rates. Only thing required in this case is that the PN sequences should have low cross-correlation values. Otherwise interference among different users will make the data recovery a difficult task. Highest cross-correlation value that the system is capable of handling, however,

depends on the actual circuitry. This property can eliminate the need of using pulse-stuffing technique required to establish synchronism between asynchronous users.

ii) Protocol-Free Data Transmission: Spread-spectrum multiple access system is basically code-division multiplexing. Different users are allotted different codes. The receiving station will receive the multiplexed data and will be able to recover the signal meant for it only when it is modulated by a particular code (PN sequence) allotted to it. Therefore, use of any protocol for sending data to the appropriate receivers, is not necessary.

iii) Secured Communication: Recovery of the baseband signal is possible only when the sequence length and connection of the shift register (SR) stages for generating the PN sequence are known. By increasing the number of SR stages the transmitted signal can be made to appear truely random. Therefore tapping the signal and deciphering the data is difficult if the exact PN sequence is not known.

Although the data rate in fiber-optic link can be made very high, it is not without limits. This limitation in terms of maximum data rate capability arises due to the dispersion

the light energy has to suffer while propagating through the channel (considered as light wave-guide). This bandwidth limitation of the channel may become the source of trouble in some applications. For example in a trunk line it may happen that after a few years demand will exceed the channel capacity, due to the ever increasing number of subscribers. Also in a communication network where different users are operating from different places, we need some efficient and easy method of adding or dropping a channel at different points in the line. Wave-length division multiplexing scheme (WDM) can be employed to meet these two demands. Optical property of the channel has given rise to this powerful technique which can enhance the channel capacity as well as provide an easy and efficient way of adding or dropping a signal at some intermediate points in the line.

1.3 WAVE-LENGTH DIVISION MULTIPLEXING SCHEME:

In this scheme different sources are used to send signals at different wave-lengths. Each source can use the channel at its highest capacity. At the receiver end these sources can be optically separated and subsequently fed to the receiver modules. These ~~two~~ signals are separated in the optical domain having been allotted definite and regular wave-length bands. Therefore, the received optical

signal should be optically separated before carrying out any electrical processing. Loss, dispersion and other important parameters in optical fiber are strongly dependent on wavelengths. Hence to ensure that all the channels have similar characteristics and to maximize the number of channels to be multiplexed within the low-loss region of wavelengths, they should have as small separation as possible without interfering with each other. This in turn depends on the wavelength spread of the sources used. Although LED's are till now extensively used as sources for optical fibers due to their better linearity, greater reliability, lower cost and easy availability, they suffer from greater spread in wavelength (of the order of 40 nm). This is the reason why laser sources are particularly attractive in case of WDM. Their wavelength spread is about 2 nm. Number of channels that can be multiplexed in wavelength using laser sources is many times greater than what can be obtained using LED sources. This number is limited by the width of the low attenuation wavelength region of fiber and the insertion loss one has to suffer for adding channels. This insertion loss is one of the three most important considerations for all types of WDM schemes reported so far; the other two being cross talk and interference between two adjacent channels.

1.4 WDM-SSM SIGNALLING:

As indicated earlier, WDM technique can be easily and efficiently used to add a signal at some intermediate points in the line. If each user is using spread-spectrum modulated signal, at each node it is only necessary to add the local signal with the incoming signal and send the combined data in the line. Recovery of the base band signal from the received data is not necessary. For such spread-spectrum multiple access system, at each node wavelength division multiplexer can be used. When only electrical characteristics are concerned, wavelength division multiplexing unit is a perfectly linear passive adder which is capable of handling data rates of arbitrary high value. Most interesting feature of this adder is that basically there is no upper or lower limit on the data rate of the signal. The upper limit is, however, imposed by the channel bandwidth, source and receiver response times and other associated circuitry, but not by the adder. Moreover in other schemes, the requirement of recovering data from the modulated carrier using detector, amplifier, limiter, data acquisition circuits at these nodes can impose additional restriction on the data rate. In this SSM-WDM combined scheme, at the receiver end the composite signal is detected, amplified to proper level and fed to the

different receivers. The receiver circuits can extract the required data in spite of the presence of other signals by cross-correlating received data with the local sequence.

In the present work two signals at different wavelengths have been combined together to form a WDM multiplexer. Optical separation of these two signals at the receiver end making use of the wavelength separation of these two signals has not been possible due to the non-availability of wavelength sensitive or angularly dispersive optical components. The separation of the signals, however, has been possible by two spread-spectrum modulated signals through these two channels. Since the WDM multiplexer here is essentially an adder, the wavelength separation of the source LED's is of no consequence. Also this scheme cannot enhance the capacity of the channel. Apart from these limitations, it provides us with the facility of combining two signals without using detector and additional sources at each node of the network system. This will reduce the cost with very little sacrifice in efficiency caused by the passive adder.

1.5 THESIS OUTLINE:

The contents of different chapters from second to six are given below sequentially.

In the second chapter different possible schemes of WDM multiplexers and demultiplexers reported so far have been discussed. Details of the WDM scheme implemented and its different losses have also been indicated.

In the third chapter principles of operation of spread-spectrum multiple access system (SSMA) and design and hardware implementation of SSMA transmitter and receiver for digital signals have been discussed.

In the fourth chapter combined SSM-WDM schemes have been described in details and their performance evaluated.

In the fifth chapter pre-amplifier and LED driver circuits and linear and adaptive delta modulators used as source coders have been described.

In the concluding chapter some results have been given and discussed and suggestions for further work have been included.

CHAPTER 2

WAVE LENGTH DIVISION MULTIPLEXING (WDM)

2.1 INTRODUCTION:

Wavelength division multiplexing (WDM) is a new multiplexing technique peculier to optical fibers. This technique can be used to increase the capacity of a fiber optic communication system. The basic block diagram of WDM is given in Figure 2.1.

The principle of operation of WDM can be explained in the following manner. Signals from several optical transmitters each emitting at different wavelengths are launched into the same fiber optic channel. The device which performs this multiplexing operation is called WDM multiplexer. At the receiving end these signals are separately detected according to their wavelengths and fed to the corresponding electrical receivers. The device used for this wavelength separation is called WDM demultiplexer. Each source being multiplexed can operate at the highest speed the channel can support. Therefore, the channel capacity can be increased as many times as there are such signals getting multiplexed.

WDM may be very useful in trunk lines where the demand often exceeds the channel capacity after a few years

of use due to ever increasing number of subscribers. WDM scheme can provide an economic and attractive solution to this problem without any significant change in the system, like change of cable, redesigning any major circuit etc. Although conceptually there is no limit to the number of channels we can add by this scheme, some serious practical problems limit this number to four or five in the low wavelength region. These problems include insertion loss, inavailability of sources at different closely spaced wavelengths, interference between adjacent channels, etc. and the low loss window width of the ~~wavelengths~~ fiber used. Several WDM schemes have been reported so far. Each method is an improvement over the previous one, either in terms of loss or in terms of interference or both. A few such WDM schemes are discussed in the following section.

2.2 WDM SCHEME : A REVIEW

A. Using Interference Filter and Beam Splitters:[8]

This method is relatively straight-forward and can be used successfully when only two sources are being multiplexed. Due to large insertion loss caused mainly by beam splitters having flat response over a wide wavelength, this method becomes inefficient when more than two sources are used. The scheme is shown in the following diagram (Fig. 2.2).

Immediately after the source fibers, collimating lenses are used to make the diverging beams coming out of fibers into collimated parallel beams. This creates space to introduce the optical components for multiplexing before it is finally focussed into the transmission fiber by a focussing lens, without suffering any significant loss. At the multiplexer end there are no wave-length sensitive devices (beam-splitters having 50% reflectivity and 50% transmission are also wavelength insensitive over the wavelength region of our interest). In the demultiplexer in addition to these components wavelength sensitive devices like interference filters* are used to separate the signals according to their wave-lengths. Although conceptually very simple, this method suffers from the following disadvantages which make it inacceptable when number of sources is large [greater than three].

a) Large Number of Components:

For one additional source we have to add two components at the multiplexer end and three at the demultiplexer end. This increases the cost, calls for larger spacing between the collimating and focussing lenses and brings down the efficiency of the system.

b) Losses:

Each beam splitter introduces minimum 3 dB loss for optical sources. Moreover there are losses associated with lens arrangement due to aberration (this is present in other systems also where lenses are used), interference filters etc. If we assume that these losses (other than beam splitter) to be 0.5 dB, total loss of this system becomes 7 dB (including multiplexer and demultiplexer) for each signal source. If one more source is added, worst case loss becomes double,-14 dB. This may be inacceptable in many cases.

Improvements:

Several suggestions have been made for the improvement of this scheme keeping the basic structure the same.

i) If the two wavelengths are far apart, one can get away with one interference filter only as suggested in Fig.2.3 [9]. This is possible because of the fact that detectors used do not have a flat response over the entire wave-length. For example, silicon detectors (say APD) can detect radiation around 850 nm wavelength region but do not respond to any radiation at 1300 nm wavelength. InP/GaInAsP detectors can detect radiation at 1300 nm wavelength. They, however, respond to radiation at $\lambda = 850$ nm also. Therefore we can select $\lambda_1 = 850$ nm, $\lambda_2 = 1300$ nm and at the receiver end

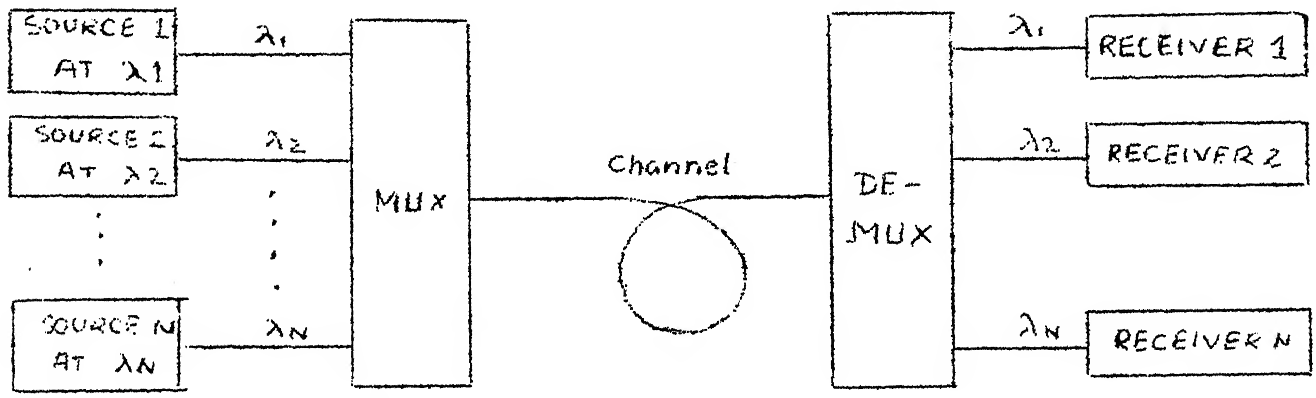


FIG 2.1 BASIC BLOCK DIAGRAM FOR WDM

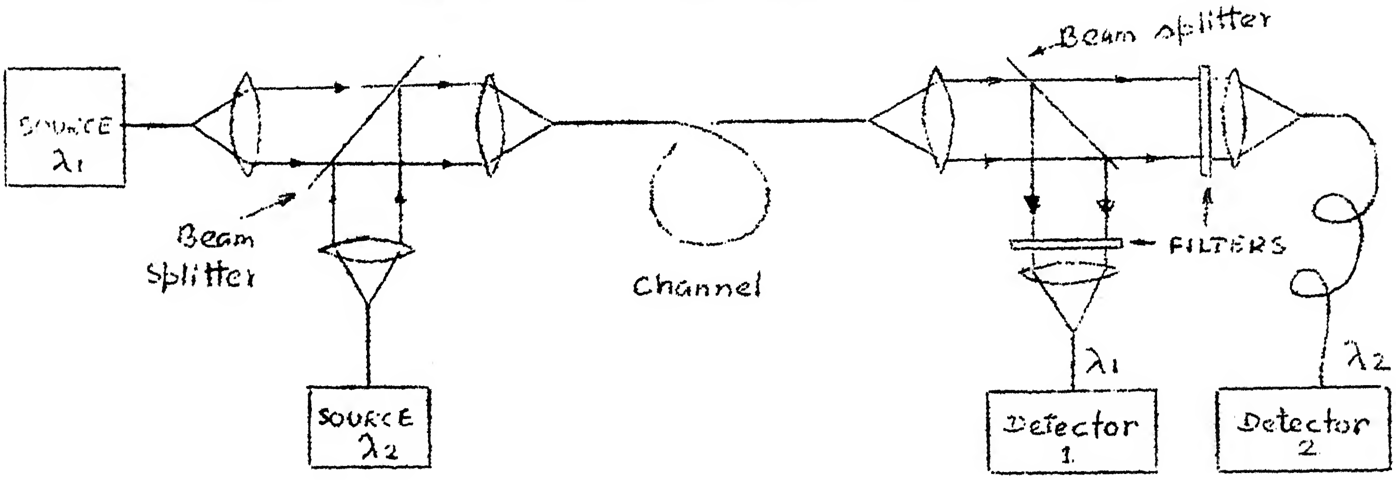


FIG 2.2 SCHEMATIC DIAGRAM OF WDM SYSTEM USING BEAM SPLITTER AND INTERFERENCE FILTERS

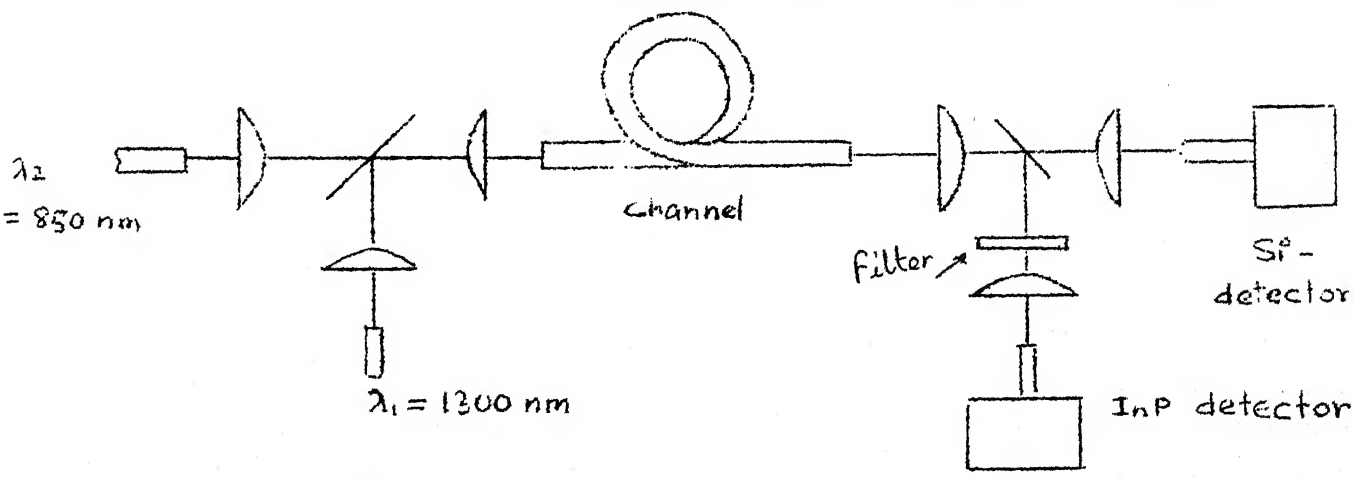


FIG 2.3 WDM SCHEME USING SINGLE INTERFERENCE FILTER

if one silicon and other InP detectors are used we need just one filter tuned at 1300 nm. The major disadvantage of this system is that the choice of wavelengths becomes restricted.

ii) Changing the beam Splitter by Wavelength Sensitive Devices:

The huge loss introduced by the beam-splitter can be reduced drastically if one can replace them by those having wave-length dependent reflectivity and transmission. Referring to Figure 2.2, we have to use cold mirrors in place of the beam-splitters, which will transmit radiation at λ_1 and reflect at λ_2. Design of such cold mirrors becomes difficult when the two wavelengths are very closely located. There is one more important advantage i.e., if wavelength response of these cold mirrors can be made resonably sharp we do not need any filters for separating the beams at the receiver end. One can, however, use filters additionally to reduce the interference still further. The most important advantage of multiplexers of this type is that its flat band response is very large. This is due to the fact that except for the interference filters other optical devices are not strongly wavelength dependent. The flat band response of this scheme depends mainly on the design of filters. Therefore due to aging if the wavelength of the source drifts, it will not degrade the performance of the system. This can eliminate

the elaborate feedback arrangement necessary for preventing the shift of source wavelength with time.

There are some general practical considerations which can improve the performance of WDM. These are equally applicable for other systems. They include the selection of input and output fibers according to their core dimeters. The output fiber, if possible, should have larger core diameter and greater numerical aperture than input fiber to avoid the loss due to astigmatism of lenses. If GRIN-rod (Graded Refractive Index) lenses are used, the system can be made more rugged, reliable and efficient. We will come to this point at the end of this section.

B. Using Blazed Plane Gratings [10]:

In terms of economy of components and the overall efficiency of the system, this scheme is by far the best. This scheme in block schematic is given in Fig. 2.4.

Due to the angular dispersive nature of the gratings the angle of ~~reflection~~ diffraction (in case of reflection type of grating) depends on the wavelength. In case of ordinary gratings this resolution is prominant only in the secondary spectrum in which 10% of the total energy is concentrated. To increase the efficiency blazed gratings are used preferably

with gold coating, so that wavelength resolution can be obtained in the principal spectrum also. The attractive features of this scheme are listed below.

i) Fewer number of components: This scheme requires just one grating in addition to the lense-arrangement. Moreover the number of components does not increase as the number of signal sources to be multiplexed increases. Therefore the number of channels can be made much higher than that possible in the earlier scheme. For increased number of channels, problem may arise for accurately placing the output fibers in close proximity.

ii) Low loss: Insertion loss caused by the blazed reflection type grating can be made only 0.8 dB as reported by Aoyama et.al. [10] (compared to 3 dB loss in case of beam splitters). This loss remains the same even if the number of channels are increased. This makes it possible to have large number of channels multiplexed without sacrificing the efficiency of the system. As many as 10 such channels have been reported.

To have a sufficiently large flat-band response it is important to have output fiber core diameters greater than that of input fiber. Wider the flat-band response less is the aging effect. Again we can not have another source emitting

at a wavelength around that flat-band of the other source. It is always advisable to keep the wavelengths as close as possible so that number of channels can be made large. Therefore one has to compromise between these two factors while designing the entire system.

Several improvements over this basic schemes have been reported. They have aimed at to the reduction of the number of components and thereby decreasing the loss of the system.

i) Modification over the previous set up to have a Littrow mounted grating [11]. By this arrangement loss suffered at the grating can be minimized. Demultiplexer block diagram is given in Fig. 2.5.

The demultiplexer has five channels in the 0.8 μm wavelength region. Insertion loss is 1.7 dB in each channel. Cross talk at the center wavelength in each channel is less than -30 dB. Using a large core (130 μm) output fiber a flat passband of 9 nm has been obtained.

ii) Using concave grating[12,13]: In this arrangement the concave reflecting surface is used for focussing. No separate lenses are required for collimating or focussing the beam. Therefore, the losses associated with lenses and the necessity of using anti-reflection coating over the surface of the lenses can be eliminated altogether. The input light

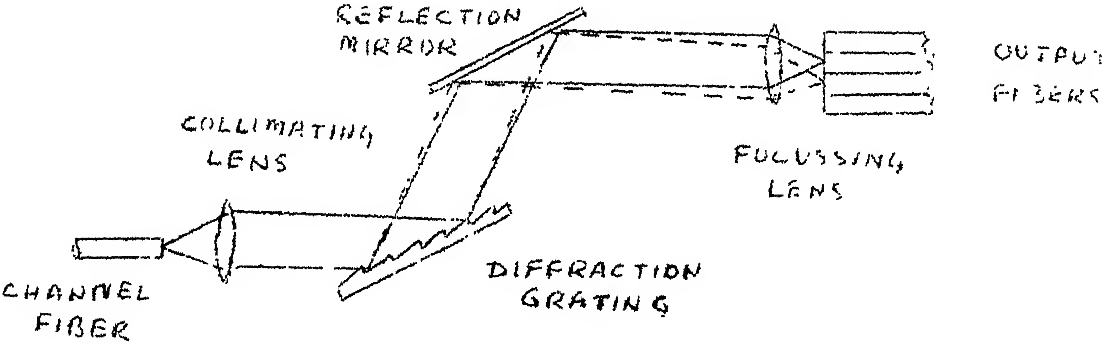


FIG 2.4 WDM DEMULTIPLEXER USING BLAZED REFLECTION GRATING

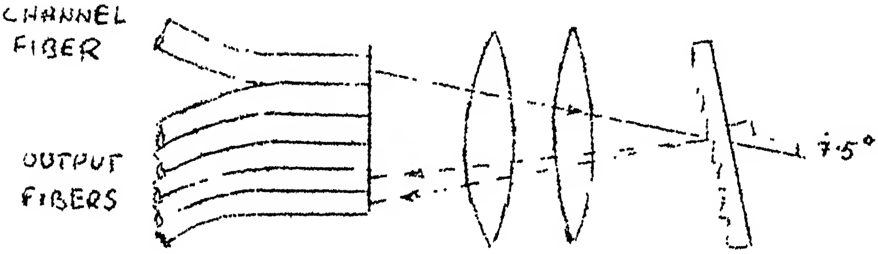


FIG 2.5 DEMULTIPLEXER BLOCK DIAGRAM IN LITTROW MOUNTING

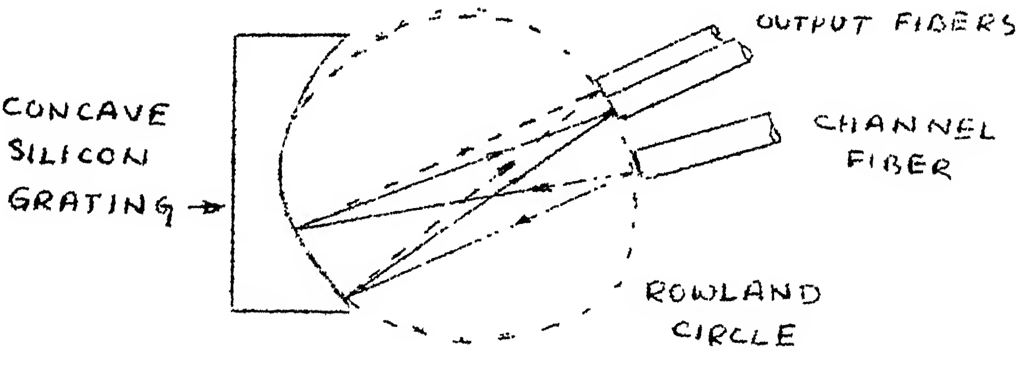


FIG 2.6 WDM DEMULTIPLEXER USING SILICON CONCAVE GRATING

containing multiple wavelengths is radiated from input fiber, diffracted and focussed stigmatically by the concave grating. In block schematic the arrangement is given in Fig. 2.6.

The efficiency achieved in this arrangement is greater than that of any other methods described here. The sources of loss are diffraction loss by grating (1.7 dB), reflection loss from the output fiber surface and the coupling loss. Cross talk at each center wave-length has been reported to be -30 dB. To increase the efficiency still further the concave surface can be made as a Rowland circle where the angle between the main diffraction facet and cylinder tangent facet must be constant throughout the rolled area.

From the previous discussion we can safely say that using diffraction grating we can have compact, efficient WDM system with considerably large number of channels. Mechanical arrangement for positioning the fibers and gratings, however, should be more precise.

C. USING PRISM [8]:

Prism being another angularly dispersive optical device can also be used in WDM scheme. Although it can offer efficiency of the same order as can be achieved by using gratings, they are seldom used due to the large size required.

WDM demultiplexers using gratings and prisms (both being angularly dispersive devices) · work with same principle of operation. The block schematic as shown in Fig. 2.7 shows a WDM scheme using prism.

As explained earlier lens arrangements are necessary to make the diverging beam coming out of input fiber into collimated one so that sufficient space can be obtained before it is focussed into the transmission fiber. Significant improvements of the system can be achieved if one uses graded refractive index rod (GRIN-rod) lenses instead of conventional homogeneous lenses. Problems encountered with homogeneous lenses are

i) We need fairly large NA lenses with negligibly small aberration and astigmatism. This needs an array of several lenses making the mechanical assembly very complicated.

ii) Free space is left between the lens and the fiber assembly. There it may accumulate dust and thereby increase the insertion loss.

iii) Anti-reflection coatings are needed.

iv) If the source is away from the lens-axis the receiver fiber has to be placed correspondingly away from the

axis at an angle with the principle-axis. This makes it difficult to mount the fibers when there are many channels.

2.3 USE OF GRIN-rod LENSE IN WDM TECHNIQUE:

These difficulties can be removed using GRIN-rod lenses [14]. These lenses are cylindrical in shape and the refractive index gradually increases as we move towards the principal axis. Following the ray-optics analysis the path followed by a light ray inside the GRIN-rod lens is depicted below. Due to their structures it has similarity with graded-index fibers as shown in Fig. 2.8.

GRIN-rod lenses are made with length L/4. At this point as can be clearly seen from the following expanded view, the output beam is a collimated one (Fig. 2.9).

Fibers can also be glued to the planer surfaces of the lens using some refractive-index matching cement. This will result in a rugged and dust-free system.

If Graded-index fibers are used,the resulting aberration of the entire assembly can be reduced by a factor of three compared to the system using homogeneous lenses. This is probably due to the inherent structural similarity of between the lens and the fiber.

There is one important angular characteristic of the GRIN-rod lenses. It can be seen that even if the source fiber

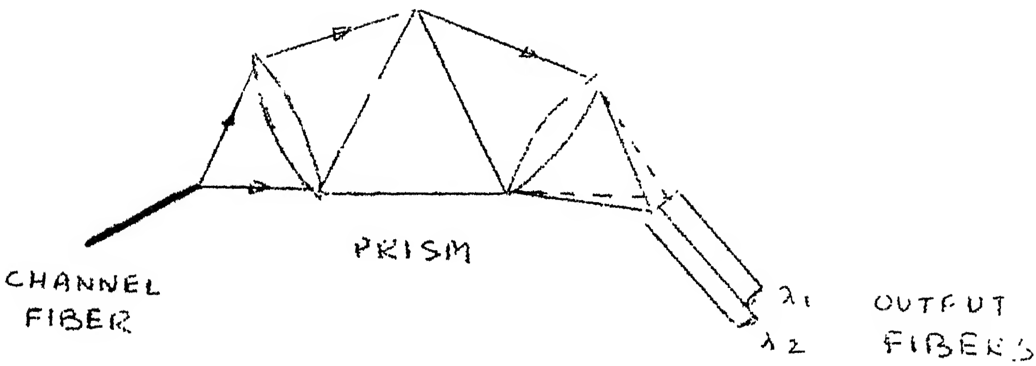


FIG 2.7 WDM DEMULTIPLEXER USING PRISM

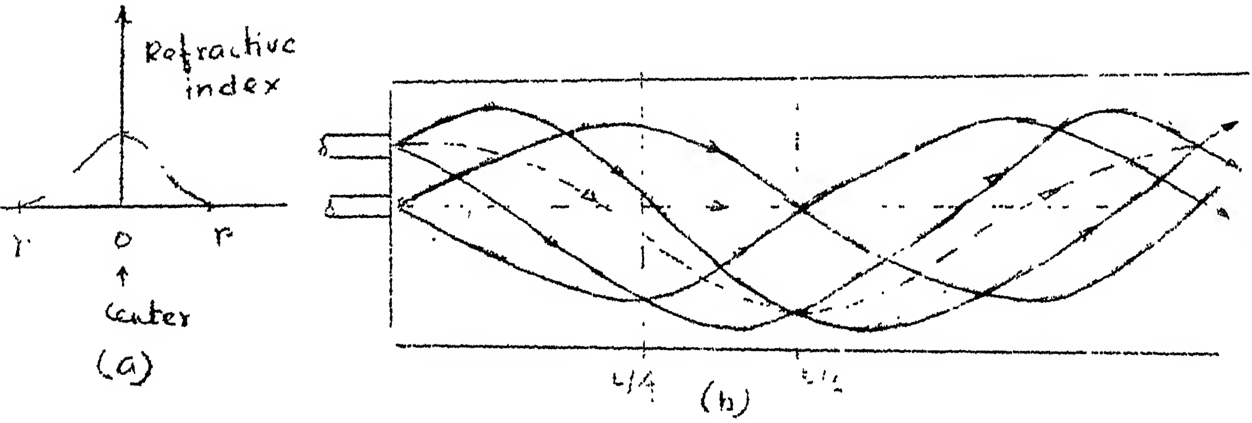


FIG 2.8 (a) Refractive-index profile
(b) Path followed by light rays in GRIN-rod lens

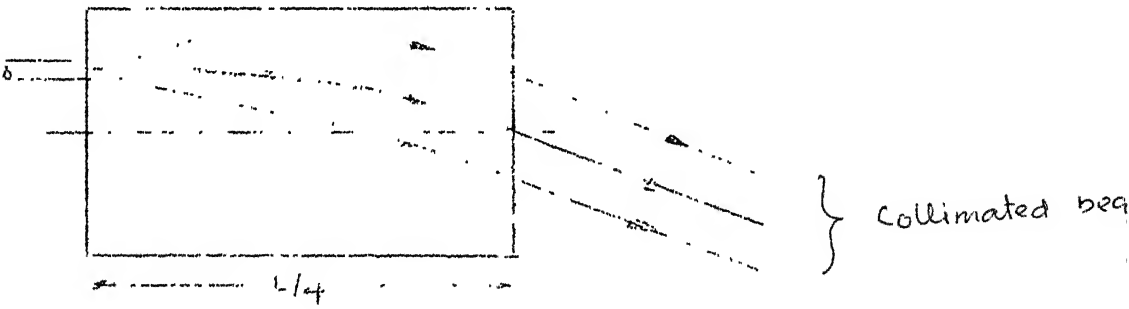


FIG 2.9 GRIN-rod lens being used to collimate rays

is off the lens axis we do not need any complicated angular positioning of the output fibers. The output fiber can be conveniently placed parallel the lens-axis. This is illustrated in Fig.2.10 where the collimating and focussing lenses are placed together.

Besides these, it is possible to fabricate GRIN-rod lenses having very small focal length ($\sim$ millimeters) and large NA to match the fiber outputs and they can perform much better than the homogeneous lenses.

Making use of these characteristics of the GRIN-rod lenses simple, rugged and efficient WDM multiplexers are possible to be fabricated. One such scheme is shown in Fig. 2.11.

Instead of using broad-band beam splitters if filters are chosen to have reflectivity and transmission that very significantly with the wavelength of the incident beam, insertion loss can be made very small. For such filters it is necessary that the beam is incident normal to the filter to reduce the polarization dependance and other problems. If the length of the lens is made large this condition can be achieved. A more elaborate arrangement for an alternate wave-length division multiplexer has been shown in Figure 2.12.

Significant improvements can be achieved in the WDM multiplexing scheme using blazed grating if GRIN-rod lenses are used [15]. Instead of using two lenses, one for collimating and the other for focussing, only one GRIN-rod lens can do the job as indicated in Fig. 2.13.

The space between the lens and the grating can be filled with a wedge shaped dielectric spacer so that the entire device can be cemented together into a stable solid assembly. Also by this arrangement a Littrow mounting of the grating is possible. Reported loss contribution in such a grating multiplexer is given below.

Bending and misalignment loss	=	0.4 dB
Aberration loss	=	0.8 dB
Element loss	=	0.8 dB
Total	=	2.0 dB

Cross talk at the center wavelength -30 dB. The experiment was carried out with two wavelengths at 1.30 µm and 1.37 µm.

Another WDM scheme has been reported [16] in which no optical multiplexer or demultiplexer is necessary. This is possible by using the light source that emits several colours and a photo-detector that has ability to demultiplex the incident light. This multicolour LED is a combination of

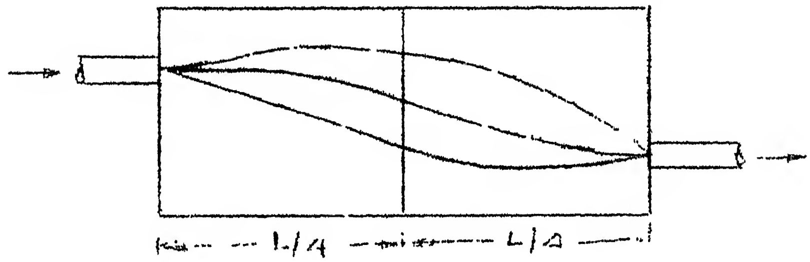


FIG 2. 10 OFF-AXIS ALLIGNMENT OF FIBERS

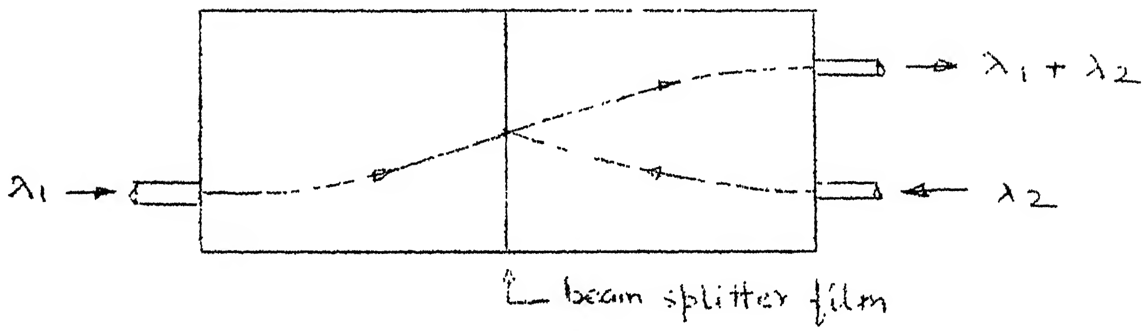
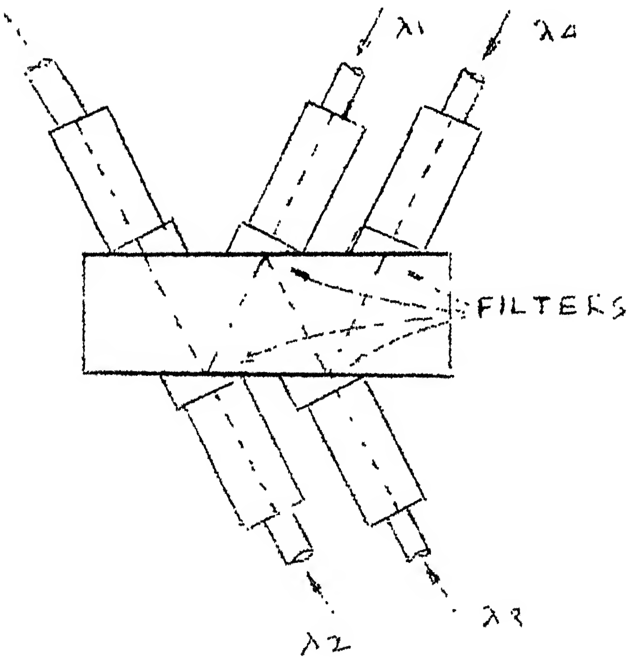


FIG 2·11 WDM MULTIPLEXER USING GRIN-rod lens



2.12 Multichannel WDM MUX using GRIN-rod lenses

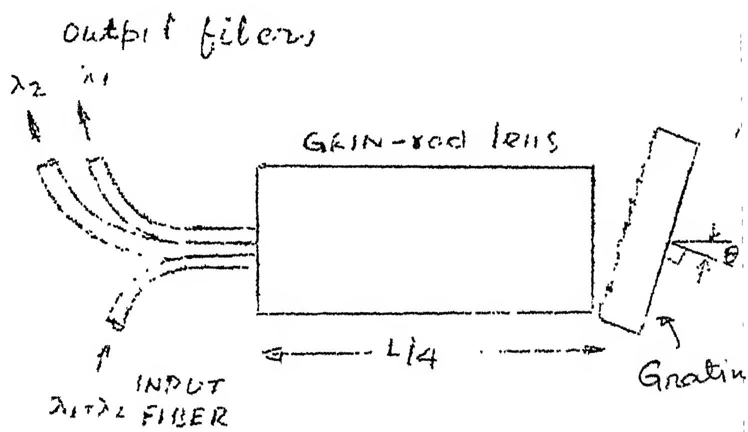


FIG 2.13. WDM DEMUX using Littrow mounted grating and GRIN rod lens

several LED's fabricated at different layers grown on an InP substrate as shown in Fig. 2.14

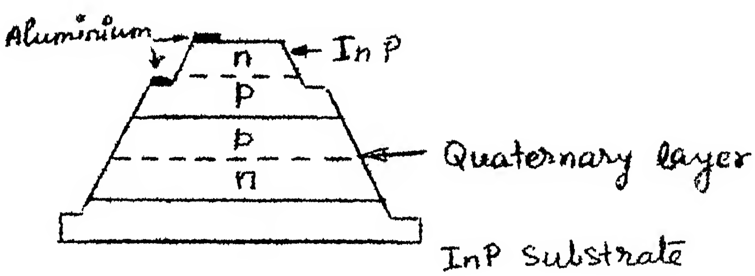


Fig. 2.14 : Multi-layered diode structure for WDM scheme.

The band-gap energy of the upper p-n junction diode is greater than that of the lower ones so that it does not absorb the radiation coming out from the lower diodes. At the receiver end also photo diode structure remains the same. In GaAsP or InP has been used in the quaternary layers. This alloy can entirely cover the low spectral window of optical fiber while keeping the lattice matched condition with InP substrate. Also due to its direct energy gap in the absorption band, the photo absorption coefficient is large. Thus the required thickness of the layer to maintain the filter action is thin, while the decrease in absorption coefficient at the band edge is sharp, which results in the narrow spectral transition region of the fabricated diode.

2.3 SYSTEM IMPLEMENTATION: WDM

In the present work a WDM multiplexer has been implemented using a wave-length insensitive broad-band beam splitter, collimating and focussing lenses. The system has two channels. Two LED sources used for this purpose emits at 820 nm and 900 nm wavelengths. Each LED has wavelength spread of approximately 40 nm (as provided in the manufacturer's data-sheet). All the optical devices are mounted on X-Y-Z manipulators placed on an optical bench for proper allignment.

820 nm wavelength source is a pig-tailed LED whose specifications have been provided in the Appendix. The driver circuit described in Sec. 5.1 is being used for driving a current of 100 mA through this LED. The driver circuit and the pig-tailed LED is housed into a cabinet and it is fixed one side of an aluminium sheet having V-grooves running through its center. The fiber ~~fib~~ was strapped into one of the V-grooves. The entire assembly is fixed rigidly on a X-Y-Z manipulator.

900 nm source is an ITT transmitter module which includes the driver circuit and the LED. Specifications is given in the Appendix. The output from this source was taken out with piece of fiber (core diameter 60 μm).

At the other end of the fiber, the outer jacket was taken out and the bare core plugged into a micro-positioner. The micropositioner was then mounted on a X-Y-Z manipulator. The X-Y-Z manipulator was used for coarse adjustment and the micro-positioner for finer adjustment.

The output fiber having core diameter $\sim$250 μm , was also alligned with a micropositioner. The lenses were mounted on fixed stands placed on the optical bench using L-shaped lens holders. The beam-splitter was mounted on a stand having a rotational motion in addition to X-Y-Z movement. The rotation is necessary to set the proper angular orientation of the beam splitter. The entire system has been described in Figure 2.15

To reduce the insertion loss the output fiber was selected with much larger core diameter than input fibers. The lenses used are microscope objectives to minimize the aberration and astigmatism. The numerical aperture (NA) of each lens is 0.25 which is greater than the largest NA of the fibers used. This will also reduce the insertion loss. The output fiber, optical devices and 820 nm source are placed on the same optical bench for proper allignment. The 900 nm source and the corresponding collimating lens were placed on separate mount so that the two collimated beams from these two sources are normal to each other.

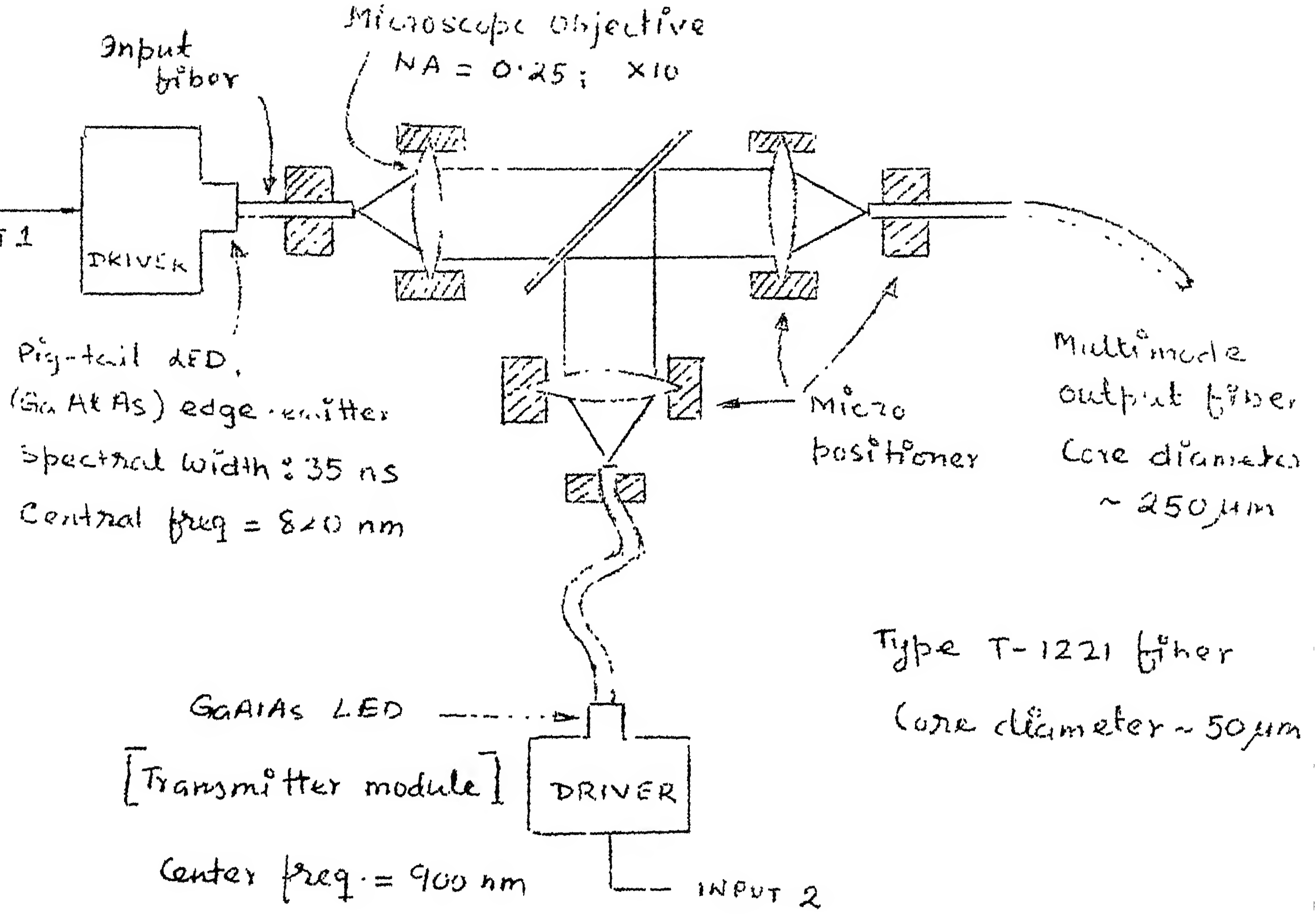


Fig 2·15 : WDM MULTIPLEXER DETAILS

The WDM demultiplexer has not been implemented for the non-availability of wavelength sensitive devices like interference filters or blazed gratings. The two multiplexed signals have been separated electrically using spread spectrum technique assigning different codes to the two sources. This electrical separation obviously cannot exploit all the advantages of WDM system. Still WDM-SSM combined scheme has its own advantages which may be applied successfully in some applications as suggested in Chapter 4.1.

CHAPTER 3

SPREAD SPECTRUM MULTIPLE ACCESS SYSTEM IMPLEMENTATION

3.1 INTRODUCTION TO SPREAD SPECTRUM MULTIPLE ACCESS SYSTEM (SSMA):

In recent years spread spectrum modulation techniques have given to some distinct advantages in some applications of communications which are not obtained using other conventional methods. The basic principle of this method, as the name suggests, is to spread the signal before transmitting through the channel. The resulting data rate is many times greater than the actual data rate. There are mainly three methods available for this purpose, namely Direct Modulation, Frequency Hopping and chirp Modulation [22]. It can be found from Shannon's equation for channel capacity that for spectral spread of baseband signal, this system can operate with much lower signal to noise ratio, i.e., in much noisy environment where other conventional systems will fail. This inherent interference rejection capability endows the system with a very powerful property, called 'Anti-jamming' which can be successfully employed in military applications. All the advantages of spread spectrum modulation technique are gained at the expense of bandwidth. For multiple access system, however, this problem is not so severe.

3.1.1 DIRECT MODULATION (DM) TECHNIQUE:

This technique is by far the most widely used of the three SSM schemes and it has been employed in the present work. In the following paragraph this method will be described briefly.

In direct modulation technique, the baseband signal is modulated by a pre-determined code having some desirable features like good cross-correlation property, easy and reliable reproducibility etc. Selection of code has been discussed later. Optical fiber communication being basically a base-band system; unlike the free-space systems, does not require any carrier, and hence PSK or FSK is not emplyed. The modulation is done by an Ex-OR gate where data and code are applied at its two inputs. Process gain achieved by this system can be approximately calculated using the emperical formula,

$$G_p = \text{Process gain} = \frac{\text{BW required by modulated signal}}{\text{Information Rate}}$$

In our case the information rate is 32 Kb/s and SS modulated signal is 32x127 Kb/s.

$$G_p = 10 \log 127 = 21 \text{ dB}$$

This process gain determines the maximum strength of the interfering or jamming signal the system can reject. In

our case the jamming signal strength should not be such that the signal to noise ratio goes below -21 dB. This property can also,be justified intuitively considering the principle of operation of the receiver circuit.

3.1.2 Spread Spectrum Receiver Circuit:

The SSM receiver circuit is basically a despreading arrangement. This despreading is accomplished by correlation operation. In the receiver, the same code which the transmitter uses for spreading the information signal is locally generated. The received signal is correlated with this locally generated code. Some sort of sliding arrangement is also incorporated in the receiver circuit to synchronise the locally generated code with the received code. The correlation function of a maximal length sequence in absence of any interfering noise is triangular in nature. As can be seen in Sec. 3.3, more sharp it is, better is the performance of the receiver. In the presence of any interference signal this sharply peaked correlation becomes rounded up. More the interfering noise strength, flatter is the correlation. Finally when the noise reaches its jamming threshold value the correlation function becomes almost flat and the receiver ceases to operate.

3.1.3 Coding for SSM:

In spread spectrum systems, as noted earlier, certain codes are used for modulating the baseband signal and thereby spreading the information data to generate a spread-spectrum modulated signal. There are several codes available for this purpose. Among them maximal length codes are most widely used for the simplicity in generating them and their good cross-correlation property. In such a system when there are several users, each one can be assigned a particular code (say m-sequence) and they can address the respective users who respond to a particular code. These users need not be synchronous. This asynchronous multiplexing is one of the most important advantages of spread spectrum technique. For this type of allocation of codes it is also referred to as Code division multiplexing. Number of users that can be multiplexed, however, depends on the jamming threshold of the system. This in turn depends on the bit length of the code sequence. Such a system where several users are using same bandwidth of the channel is called spread spectrum multiple access (SSMA) system.

Gold codes are another set of codes (not maximal length) which are also extensively used for their low (although greater than that for maximal length codes) and uniform cross-correlation values. Apart from these two codes Kasami

codes and some other codes can also be used for this purpose.

All these codes have one feature in common, - they are all pseudo-noise, i.e., they are deterministic sequences having properties like that of white noise. Hence if the code length can be made large enough they will appear to be noise to somebody who does not have any prior knowledge about the code itself. This property can be used for a system where message privacy is of utmost importance. This type of security is inherent to the spread spectrum system.

3.2 SSM TRANSMITTER:

Once the basic principle of spread spectrum modulation is understood, the design and implementation of transmitting becomes relatively easy and straight-forward. The principal task of the transmitter is to generate a definite pseudo-noise binary sequence which will be used to modulate the data. The modulation task is performed by EXOR operation.

In the present work a maximal length sequence using seven stage shift register (sequence length = 127 bits) has been used as the modulating signal. A block diagram of the scheme is given in Fig. 3.1. First the data clock has been multiplied 127 times using a PLL to maintain synchronism. This synchronism is necessary because one data bit should fully encompass the entire 127 bits of the maximal length

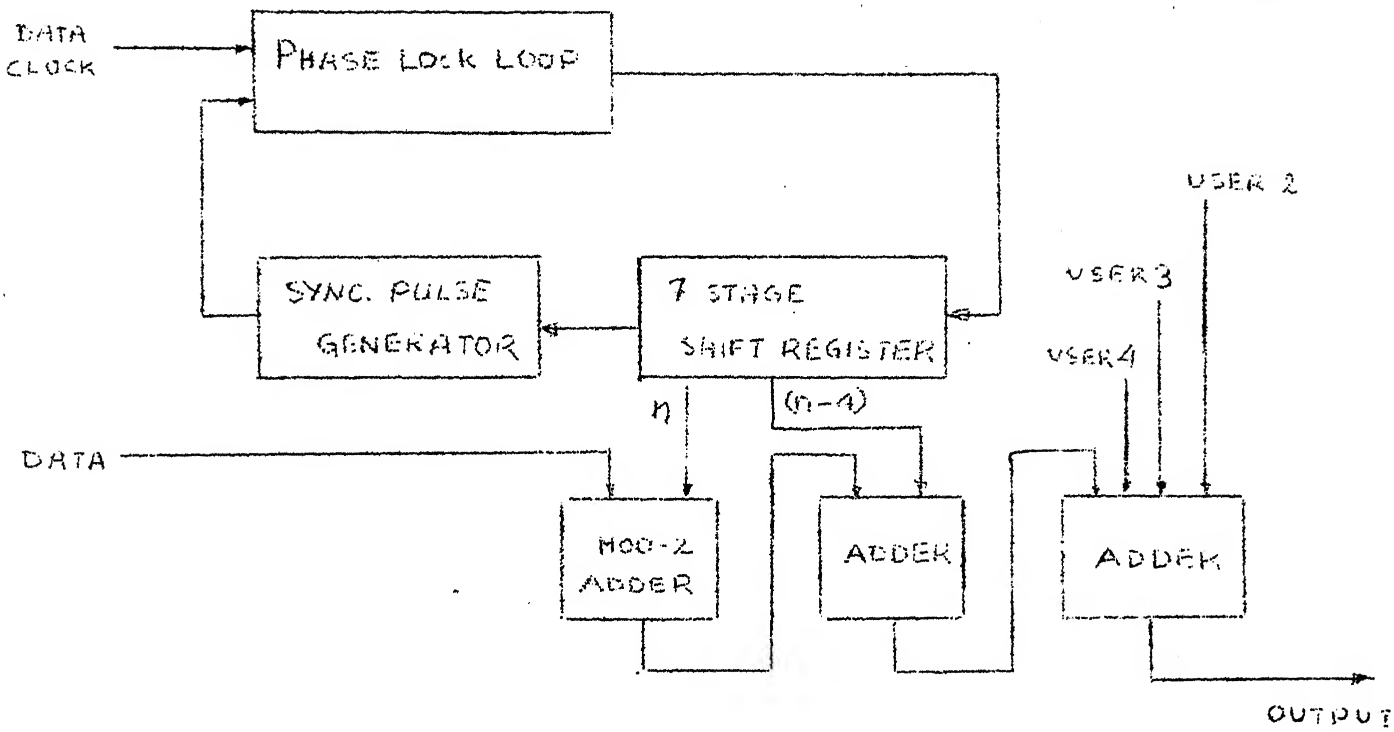


FIG 3.1 : BLOCK DIAGRAM FOR SSM TRANSMITTER

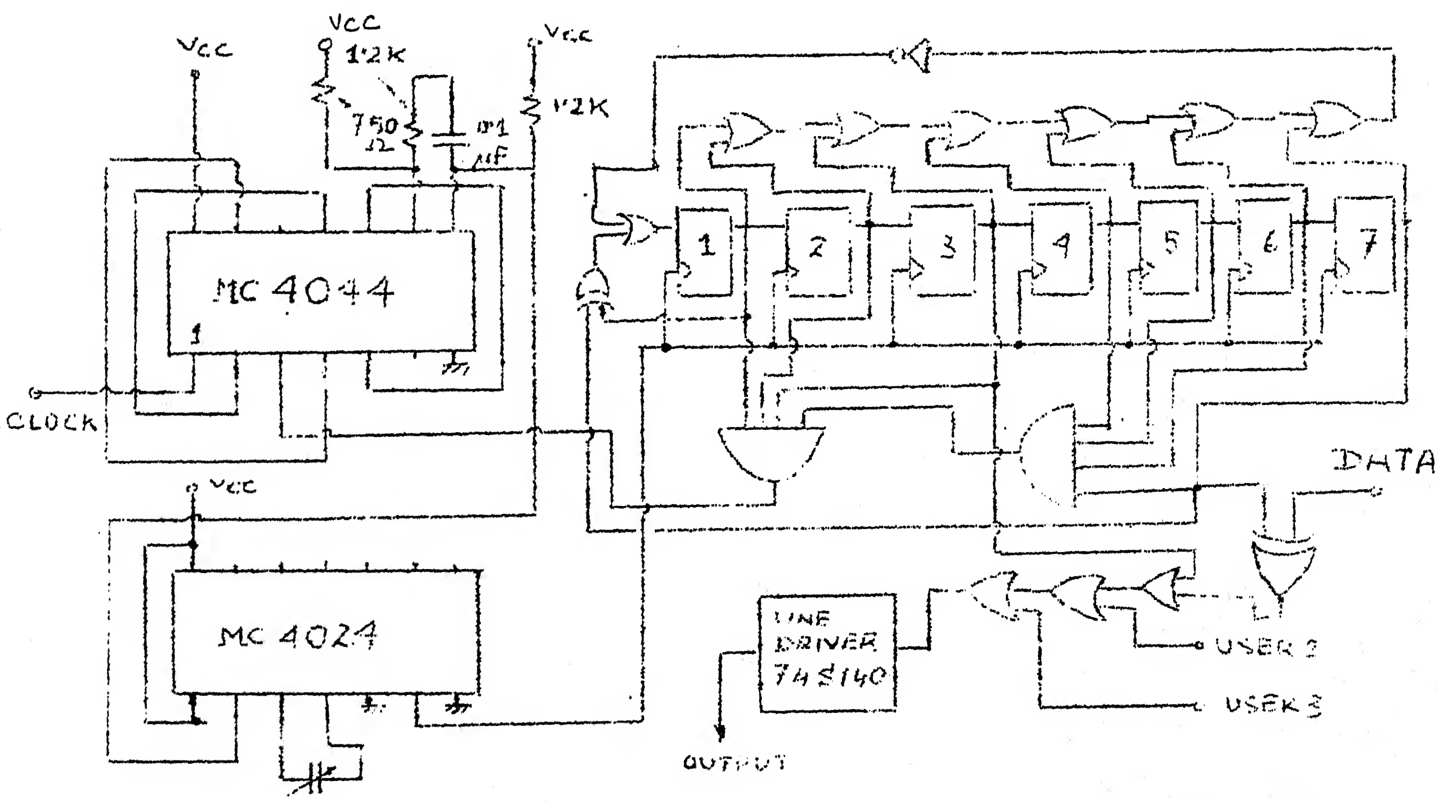


FIG 3.2 : SSM TRANSMITTER CIRCUIT DIAGRAM

PN sequence. The PLL has been realised using MC 4024 and MC 4044 chips. The sync. pulse to the PLL has been provided by using a decoder which gives a high output only when all the 7 stage outputs are '1'. This particular choice of the decoder has been made for chip economy. It requires dual 4-input AND gates which are available in a single chip. The duty cycle of this sync. pulse is only $\frac{100}{127}\%$, but it does not affect the operation of the PLL. The PLL is +ve edge triggered. A shifted version of the modulating PN sequence is sent for the purpose of synchronisation in the delay lock loop receiver. The third stage output of the 7-stage shift register is directly sent for that purpose. A simple decoder circuit, in addition to that used for generating sync. pulse to the PLL, has been used to prevent the shift register stages from entering all ~~row~~ zero states. Whenever it enters that state the decoder circuit introduces a '1' in the feedback path and its normal feedback operation starts again. This decoder circuit however remains ineffective for all other 127 states of the 7 bit SR stages. Provision has been made to add 3 more users synchronously a asynchronously using 3 additional OR gates which are essentially adders plus limiters. The circuit diagram is shown in Fig. 3.2.

3.3 SPREAD SPECTRUM RECEIVER CIRCUIT:

As noted in the introduction, SSM receiver is a

despreading circuit used to recover the base band signal from the received SSM encoded signal. The receiver has two parts to perform the following operations:

a) To generate and track the code sequence used to modulate the baseband signal.

b) To demodulate the information data from the received data pattern which contains the modulated data plus interfering noise.

There are several types of receiver circuit possible for this purpose. In the present work delay-lock-loop circuit has been used to track the signal. It is principally a non-linear feedback system which employs a cross correlation in the feedback loop to track a particular PN sequence. Here it has been used to regenerate the modulating maximal length PN sequence synchronously with the transmitted sequence. Before the received data is applied to DLL, it has been amplitude limited to two levels. The principle of operation of the circuit is given below in Sec. 3.3.1 with the help of a basic block diagram (Fig. 3.3).

After locally generating the code sequence the demodulation operation has been carried out in two stages. First the synchronizing PN sequence has been eliminated using two EX-OR gates and then the resulting signal is passed through

a second order integrator which shows peaks whenever the baseband signal is one. The decision whether the data is one or zero is taken by a schmitt trigger. Much of the interfering noise gets eliminated by this integrator and schmitt trigger, and the receiver can take decision in the presence of large interfering noise. Detailed description is given in Sec. 3.3.3.

3.3.1 Principle of Operation of DLL:

The received signal is corrupted by noise and shifted from the original and is represented by

$$\sqrt{P_s}\ S(t+\tau) + n(t)$$

Loop filter is a low-pass filter and its transfer function is $G_1\ F(P/P_o)$

VCO gain : $G_c = \frac{1}{\alpha}$ /sec/volt.

The output of the cross correlator is

$$x(t)=k[S(t+\Delta+\hat{\tau}+\ ) - S(t-\Delta+\hat{\tau})]\ [\sqrt{P_s}\ S(t+\tau)+n(t)]$$

After Taylor series expansion the input signal can be written as

$$\sqrt{P_s}\ [S(t+\hat{\tau})+\varepsilon S'(t+\hat{\tau})+\frac{\varepsilon^2}{2}S''(t+\tau)+\ldots]+n(t)$$

where

delay error

$\varepsilon = \tau(t) - \hat{\tau}(t)$ assumed to be small.

The primes refer to the differentiation with respect to the argument and all derivatives are assumed to exist.

There is one restriction under which the receiver circuit has to operate. Initially the delay error has to be small so that the series expansion of $S(t+\tau)$ about $S(t+\hat{\tau})$ converges rapidly.

$$\frac{x(t)}{k} = [S(t+\Delta+\hat{\tau}) - S(t-\Delta+\tau)][\sqrt{P_s}\left\{S(t+\hat{\tau}) + \varepsilon S'(t+\hat{\tau}) + \frac{\varepsilon^2}{2} S''(t+\hat{\tau}) + \dots\right\} + n(t)]$$

$$= \delta S(t+\hat{\tau})\,[\sqrt{P_s}\left\{S(t+\hat{\tau}) + S'(t+\hat{\tau}) + \frac{\varepsilon^2}{2} S''(t+\hat{\tau}) + \dots\right\} + n(t)].$$

where $\delta S(t) \Rightarrow S(t+\Delta) - S(t-\Delta)$.

It is closely related to the expression for the differentiated signal used in cross-correlation operation namely

$$\frac{dS}{dt} = \underset{\delta\to 0}{\mathcal{L}t}\ \frac{S(t+\delta) - S(t-\delta)}{2\Delta}$$

$$\frac{x(t)}{k} = \sqrt{P_s}\,\delta S(t+\hat{\tau}) . \varepsilon S'(t+\hat{\tau}) + \eta_e(t)$$

where

$$\eta_e(t) = \delta S(t+\hat{\tau})\,[\sqrt{P_s}\ S(t+\hat{\tau}) + \frac{\varepsilon^2}{2} S''(t+\hat{\tau}) + \dots + n(t)].$$

Following consideration will help to simplify the expression further and understand the tracking behaviour better.

a) S(t) is normalized to have unity power. Therefore the the received signal power = A^2.

b) The term $\delta S(t+\hat{\tau}).\ S'(t+\hat{\tau})$ has a non zero average value given by Pd, the power in the differentiated signal.

$$\delta S(t+\hat{\tau}).\ S'(t+\hat{\tau}) = P_d + S_2(t)$$

where S_2 has a zero mean.

$$\frac{x(t)}{k} = A\, P_d\, \varepsilon(t) + S_2(t) + \eta_e(t).$$

The tracking behaviour of this loop can be obtained from the above equation. Suppose input delay τ (t) is suddenly increased by a small amount. The delay error ε (t), initially assumed to be small also increases and multiplier output also increases. VCO characteristic is selected appropriately such that it forces the delay estimate $\hat{\tau}$ to increase and thus tracking operation is accomplished. The discriminator consisting of the cross-correlation network and the low-pass filter gives an output which is an estimate of the delay.

Throughout the analysis we have assumed that the error is small. In the following paragraph we will show that in the given configuration once the circuit gets into the 'lock-on' condition

the delay error should not exceed one clock-width for the proper tracking operation.

For a binary sequence having levels '0' and '1', the autocorrelation function stands as given in Fig. 3.4. For the operation shown in the Fig. 3.3 the output of the adder shows a characteristic as shown in Fig. 3.5.

For this closed-loop system the characteristic must have a +ve slope and the VCO should have +ve slope for proper tracking of the pseudo-noise sequence. It can be seen from the above diagram shown in Fig. 3.6 that for this condition to be fulfilled the system can faithfully track the sequence only when the delay does not exceed twice the clock-width. This gives the maximum delay error the system can handle. If delay error exceeds this value the DLL goes out of its lock and further acquisition is not possible so long as the delay does not come below this value.

Initially we have assumed that the input signal has been passed through an amplitude limiter before it is fed to the cross-correlator. This will greatly simplify the actual circuitry in implementing the delay lock tracking circuit with very small degradation in signal to noise performance of the circuit. The signal-to-noise ratio of the circuit will however come down by 1.98 dB only.

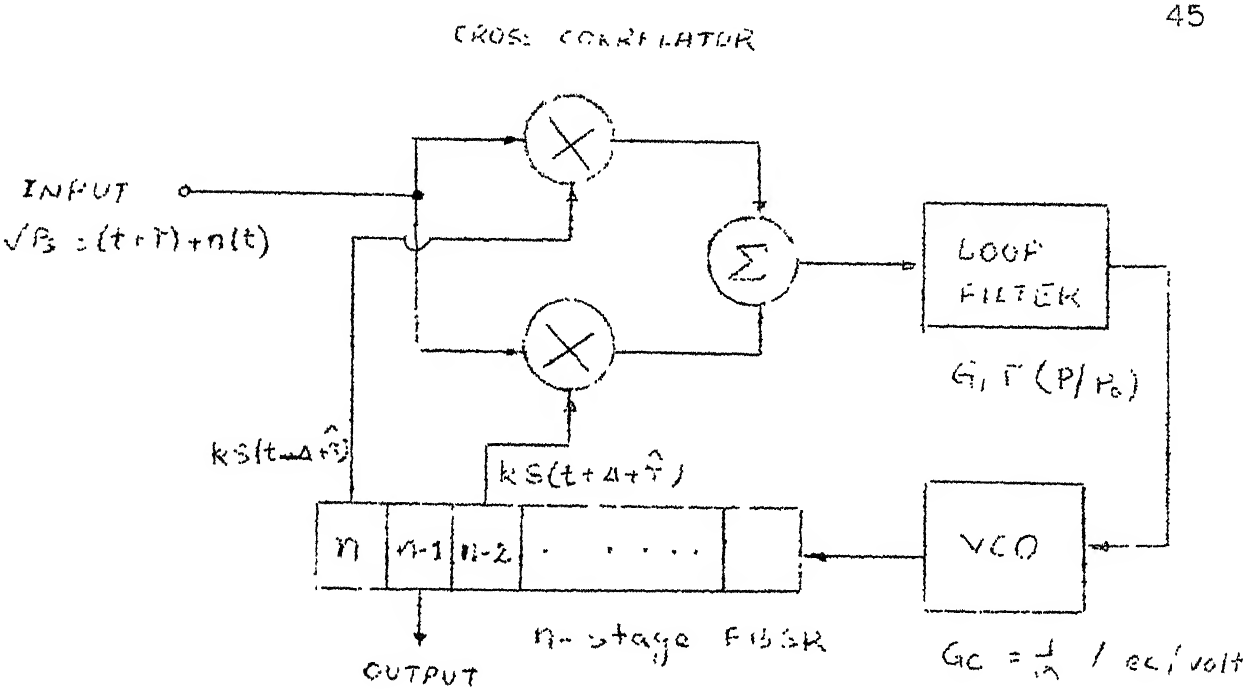


FIG 3.3 : BASIC BLOCK DIAGRAM FOR DELAY LOCK LOOP

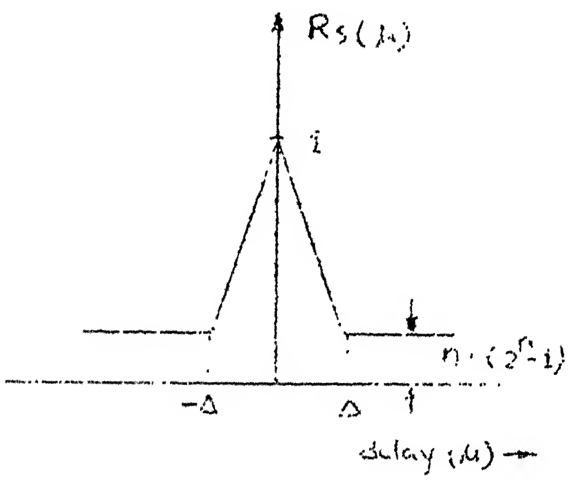


FIG 3.4 AUTO CORRELATION FUNCTION OF A PN SEQUENCE HAVING LEVELS '0' AND '1'

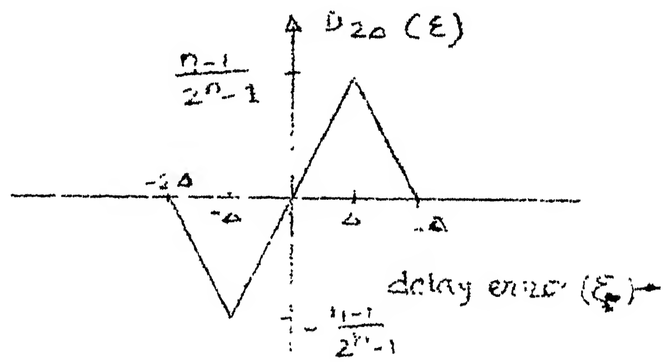


FIG 3.5 : DLL CHARACTERISTIC

We have therefore shown that a delay-lock-loop can track any pseudo-noise sequence when the sequence is known and the delay does not exceed a specified value (2Δ). Now there is another problem encountered when one wants to use it in spread-spectrum multiplexed circuit. This difficulty arises due to the fact that in SSM the input sequence is not the PN sequence itself. It is used to modulate the data. When the DLL receiver receives an inverted version of the PN sequence the discriminator characteristic gets inverted and the receiver circuit goes out of lock. This behaviour of the DLL circuit can be justified as follows.

Assume that the input is an inverted PN sequence: The correlation of this inverted PN sequence with the nth stage output of feedback shift register is as shown in Fig. 3.6(c).

The slope of the characteristic at ~~this~~ the portion where it is desired to get locked is negative. This negative slope of the characteristic drives the circuit out of lock.

This problem can be avoided by sending an additional PN sequence as it can be used for proper synchronisation. Another method would be by introducing a second feedback loop whose purpose is to invert the incoming signal whenever the base band signal is '1'. This secondary loop requires elaborate noise-eliminating circuit and also

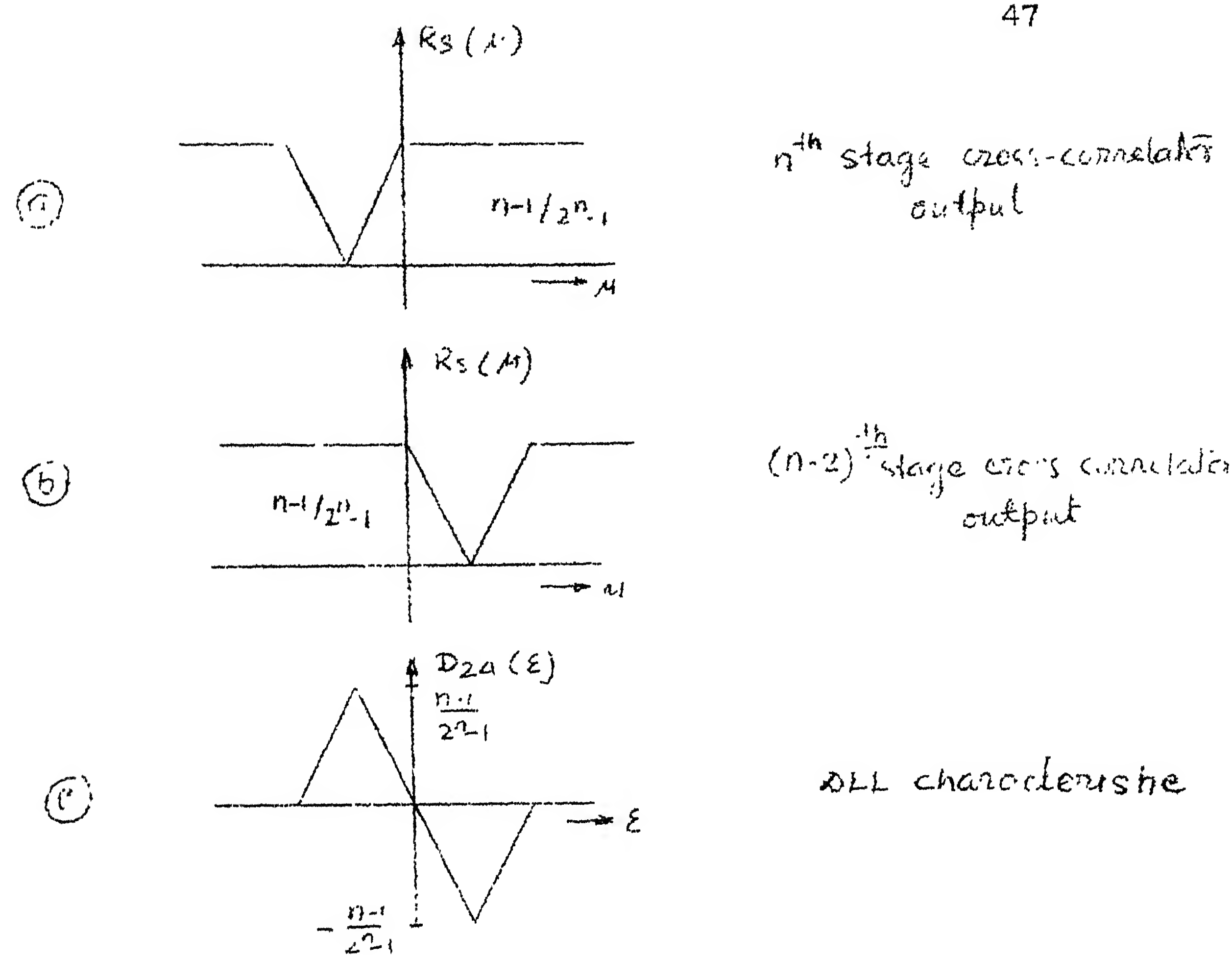


FIG 3.6 DLL CHARACTERISTICS FOR INVERTED PN sequence

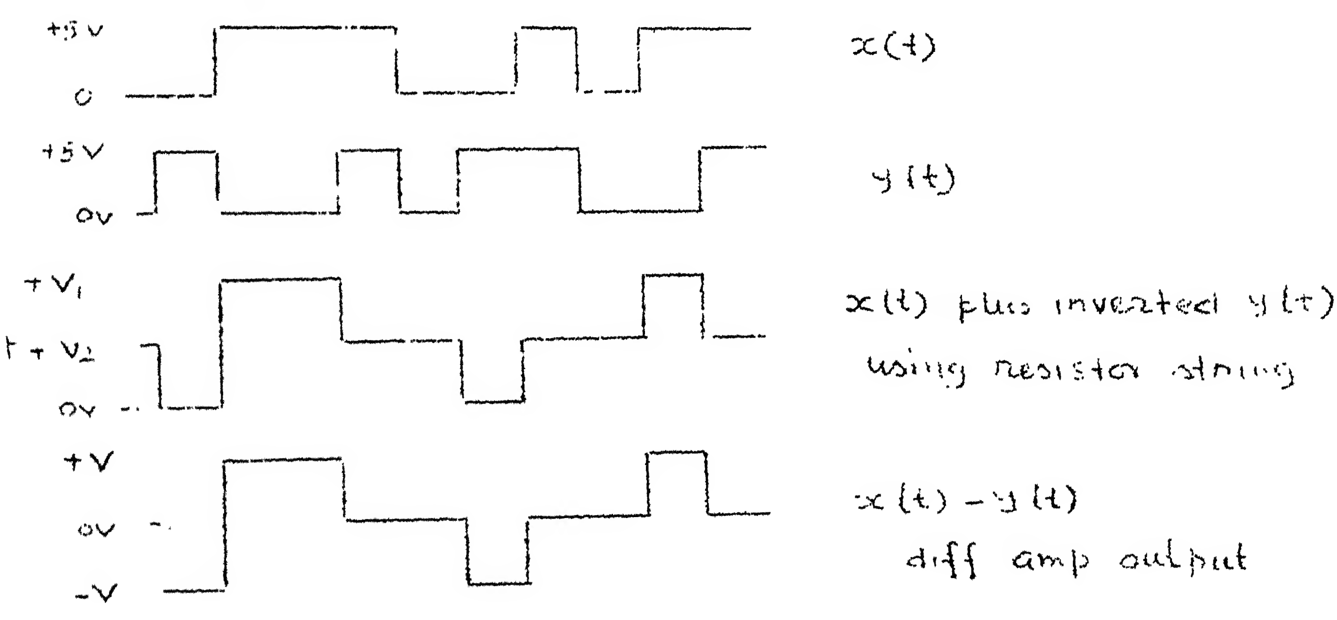


FIG 3.7

decreases the stability of the circuit significantly. The first method is, however, straightforward although it decreases the number of users to half of the full capacity when all the users are asynchronous. In the present work this method has been adopted.

3.3.2 Implementation and Circuit Description of DLL:

As indicated earlier, incorporation of the amplitude limiter at the input has greatly simplified the circuitry. Using 'cycle and add' property it can be shown that exclusive-nor operation in case of TTL binary signal is equivalent to multiplication for analog signal. Thus we can avoid analog multiplier circuits which are expensive and very difficult to implement using discrete components specially at high frequency.

In stead of using any active device for subtraction, we have used a passive adder using resistor string. The signal which is going to be subtracted is first inverted and then applied to one input of the adder, the other signal being feed straightaway. It can be shown as given in Figure 3.7 that this

combination performs the same operation. The nature of the waveform is, the same as the difference of two signals; only the output has some off-set d.c. voltage.

The loop filter was designed using a first order integrator with a lead-lag network. A bufferstage has been connected at the output of the integrator to interface it with other circuitry. Before the signal is fed to the VCO input there is one gain stage to adjust the loop gain and an adder circuit using µA 741 to elevate the error voltage above certain d.c. voltage. This is necessary because the VCO operates linearly only when the input voltage lies between +2.5V to +5 volts. The VCO output is then used as the clock to the FBSR stage and this closes the loop. The integrator resister and capacitor values and the loop gain have to be adjusted for the optimum performance of the circuit.

3.3.3 Data Recovery Circuit:

Once the DLL gets locked with the synchronising PN sequence, this PN sequence is used to get the modulating PN sequence. Also the effect of this synchronising PN sequence has to be eliminated from the input signal. Two successive EXOR operations accomplish that operation in the receiver circuit.

Once the synchronising PN sequence has been removed it is again EXORed with the modulating PN sequence and passed through a second order integrator. The integrator time constant was designed in such a manner that it integrates over one full data bit and reaches saturation. Besides faster roll down, this second order integrator has another advantage that it can be coupled to subsequent gain stage without using any buffer. Gain of the integrator was kept slightly greater than unity. This causes some oscillation at the output and it was successfully utilized to incorporate a schemitt trigger which also eliminates some noise and clock jitter. The gain and the loop-width of the schmitt trigger have to be adjusted by trial and error method to get an optimal performance. The entire circuit is shown in Fig. 3.8.

MEASURED VALUES

Performance of the SSM receiver has been measured both synchronous and asynchronous users. These values are given below.

a) Using asynchronous users

No. of users	Bit error rate
1	No error detected during 15 min. of observation.
2	''
3	0.65×10^{-5}
4	0.74×10^{-4}
5	0.31×10^{-3}
6	0.11×10^{-2}

For synchronous users no errors have been detected during 15 minutes of observation for[six such users].

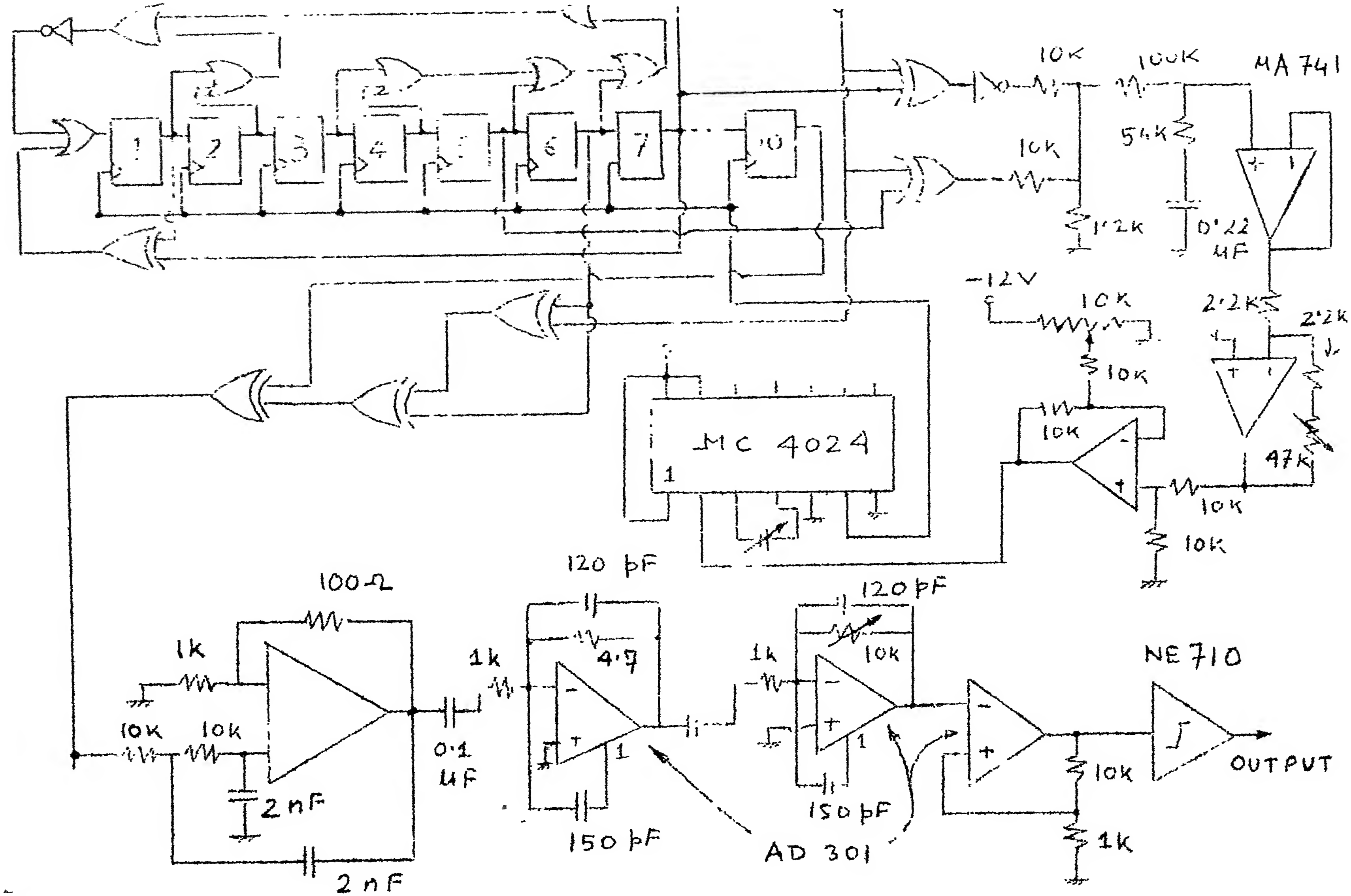


FIG 3'8 SSM Receiver circuit diagram

CHAPTER 4

COMBINED WDM - SSM SIGNALLING

4.1 INTRODUCTION:

WDM scheme has been used at the nodes where in a communication link one user wants to feed some data into the line. In conventional structure at these nodes the incoming signal is first detected, subjected to some electrical processing, added to the data coming from the local user and again sent into the channel. This becomes a costly affair mainly because of the detectors and sources ~~at~~ required at each nodes. This addition of data at nodes can be achieved using WDM multiplexer where the signals can be added optically without going through all the necessary electrical processing. In our system different users are sending spread-spectrum modulated data through the channel. They are allotted different maximal length sequences each of 127 bits. For this spread-spectrum multiple access system the users need not transmit synchronously. Therefore, at the nodes it is only necessary to ~~multiplex~~ add the two incoming signals, and this has been achieved using a WDM multiplexer. As indicated in Sec. 1.4, the wavelength separation of the sources located at different places is not necessary for the present work, because of the use of SSM techniques. If at the

receiver end WDM demultiplexer can be used, the capacity of the channel can be further enhanced. The advantages of this WDM-SSM combined system are noted below:

i) Simple node structure:

At each node we need a few optical components only. Any one of the schemes suggested in Sec. 2.1 can be used. If wavelength sensitive devices are used for this multiplexing operation like gratings prisms etc. then the sources should be at different wavelengths. Whatever method may be adopted, the node structure becomes much simpler. Otherwise, if broadband beam-splitters are used, sources can operate at the same wavelength.

ii) Perfectly Linear Passive Addition:

Perfectly linear addition can be achieved using this WDM multiplexer. Intensities from the two fibers at the node are added and the resultant signal sent into the channel. Besides insertion loss, the two signals suffer losses due to aberration and astigmatism of the lens assembly. It can be made very small using some efficient technique as suggested in Sec. 2.1. This technique, however, does not provide any gain.

iii) Cost Effective:

At the nodes we need only a few simple optical devices

like lens, beam splitters etc. Since no detectors, sources and electrical processing circuits are need, it can reduce the cost for such node structure.

iv) Recovery of Baseband signal is not necessary:

It is possible due to the fact that we are using a spread-spectrum multiple access system. This eliminates the requirements of using costly and elaborate circuitry to detect the base-band data and assign appropriate time-slots to the local users (as done in time-division-multiplexing).

v) Protocol-free Data Transmission:

In the WDM-SSM combined system it is possible to use all uncoordinated users. Therefore, no protocol is necessary for maining synchronism between different users in the line .

The present system is not without some disadvantages. The limitations of the scheme are given below.

i) No improvement of channel capacity:

As indicated earlier it is possible to enhance the channel capacity using WDM scheme. In this scheme since we are using only a WDM multiplexer for the purpose of addition, the channel capacity remains the same. One can however, use a WDM demultiplexer at the receiver end, separate

the two sources according to their wavelengths and feed them to the respective users. In this way the channel capacity can be increased or if this larger channel capacity is not needed,the interference caused by one user to the other can be further reduced.

ii) No gain in signal level achieved:

Due to the passive nature of the WDM multiplexer the signal levels of the two incoming data cannot be elevated. On the contrary they suffer from the losses associated with the multiplexer circuit as indicated in Sec. 2.1. If the detectors and additional sources are used at these points certain amount of gain can be achieved during the electrical processing of the signals and this node can as well act as a repeater station for the data coming down the channel. The passive adder, however, cannot provide this facility.

4.2 DESCRIPTION OF THE COMBINED SYSTEM:

It was intended to send a spread-spectrum modulated speech signal through one channel. The other source, which may be located at a different place, was used to send a PN sequence which would act as an interfering signal to the first source. Performance of the entire system was checked with and without the presence of the second user in the link. The entire system block diagram is given in Fig. 4.1.

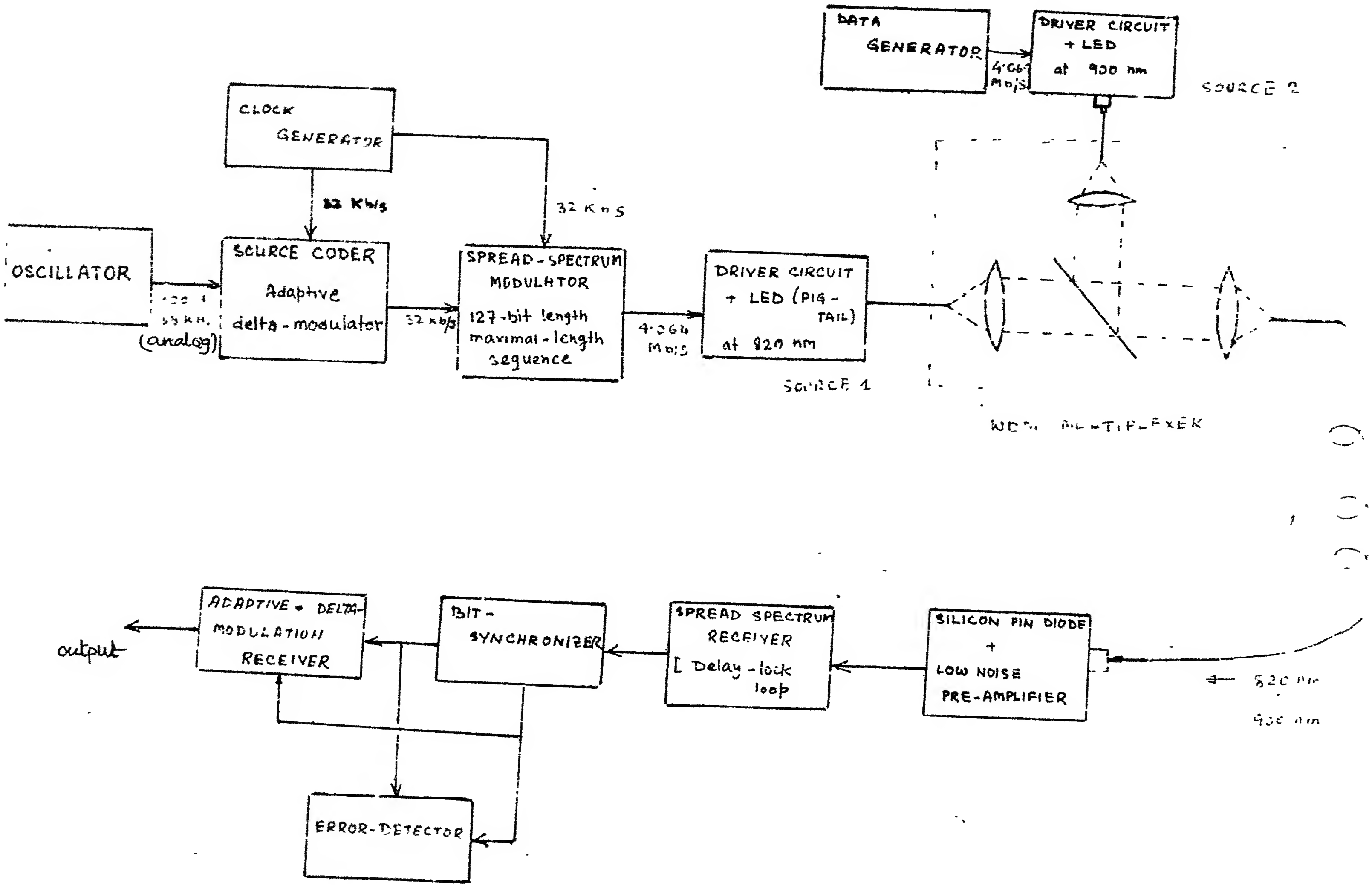


FIG 4·1 BLOCK DIAGRAM OF THE SYSTEM

The input signal was taken from a sine wave oscillator whose frequency was changed from 300 Hz to 3.5 KHz (speech bandwidth). An adaptive delta modulation circuit has been used as a source coder which encodes the input analog signal into digital data coming out in synchronism with a clock of 32 Kb/s. The details of this source coder is given in Sec. 5.4. This data is then fed to a spread spectrum modulator circuit which spreads the bandwidth of the signal 127 times by using a 127-bit length maximal length sequence. Principle of operation and circuit description have been provided in 3.2. The resultant data at 4.064 Mb/s is applied to the LED driver circuit and subsequently sent into the channel at 820 nm wavelength.

At some intermediate point in the line a WDM multiplexer has been used. One channel input is the data coming out of the 820 nm source. Another LED source at 900 nm wavelength sends data into the second input of the WDM multiplexer. This data is another 127-bit long maximal length PN sequence at 4.064 Mb/s. The two data rates are same but asynchronous to each other. They are added linearly and again fed into the channel.

This combined three-level detected signal at the receiver end, raised to a certain voltage level using the

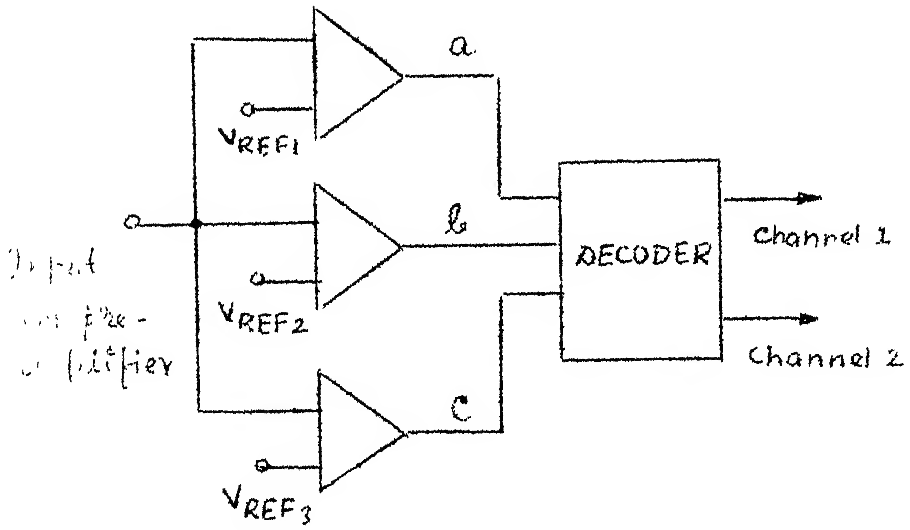
low-noise receiver pre-amplifier (Sec. 5.2) is passed through an amplitude limiter and comparator to get a two-level TTL compatible output. This data is then applied to the spread-spectrum receiver circuit using a delay lock loop. This circuit as elaborated in Sec. 3.3 recovers the baseband data from the incoming modulated signal corrupted by noise and data from the second source. The bit-synchronizer circuit extracts the clock from the received data pattern using delay and multiply technique (Sec. 5.5.1). Finally the data and clock have been applied to the adaptive delta modulation receiver circuit to get an analog output which is a replica of the input analog signal.

4.3 PERFORMANCE EVALUATION:

Performance evaluation of the system was done for various conditions as described below.

4.3.1 A Multiple Threshold Detector Circuit was used to separate the two channels. This demands the coupled power from one source to be weaker than the other. For this condition the two signals can be separated as given in Fig. 4.2.

The three reference values were set as shown in Fig. 4.3. The experimental set-up used for this purpose was as shown in Fig. 4.4.

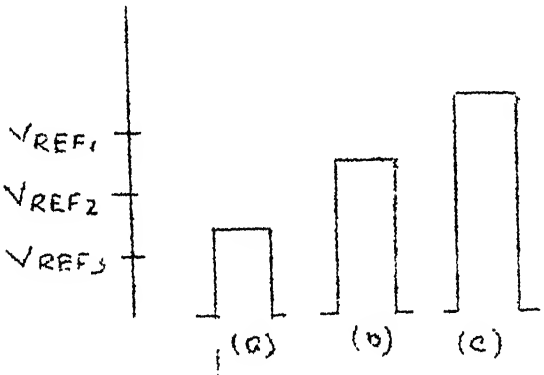


a) Gives output when both source is 'ON'

(b) Gives output when only source 1 or both of them 'ON'

(c) Gives output when any one or both the sources 'ON

FIG 4·2 BLOCK SCHEMATIC FOR THRESHOLD DETECTOR



(a) Pre-amp. output when only source 2 is operating

(b) When only source 1 is operating

(c) When both source is operating

FIG 4·3: Choice of Reference Voltages

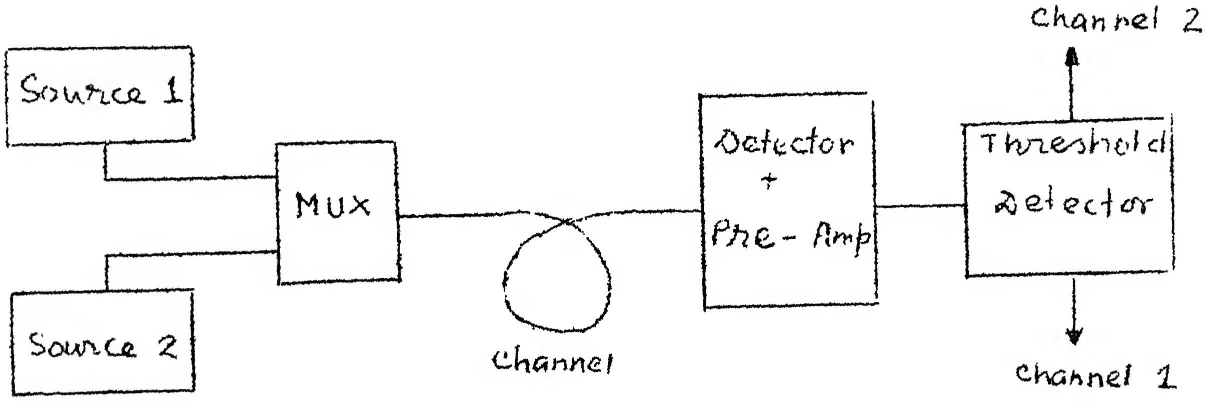


FIG 4·4 Channel Separation using Threshold Detector (BLOCK DIAGRAM)

The strength of channel 2 was reduced by keeping the input fiber slightly off-focus. The data frequencies of two channels were changed independently.

Max. operating frequency of source 1 = 6 Mb/s

Max. operating frequency of source 2 = 15 Mb/s

Due to the reduced strength of the signal from the source 2 its maximum data rate decreases.

For proper operation we need definite values of the signal strengths from the two channels. Aging effect may cause the degradation of signal strength and thereby require readjustment of the threshold circuit to maintain the operation of the link. Moreover we need ultra-stable reference levels. All these factors make this threshold detector circuit unstable to be used in any real time signalling ~~system~~ for separating the two channels. Here it was used to check the performance of the WDM multiplexer. It was not possible to measure various power levels for want of sufficiently sensitive power meter.

4.3.2 The experimental set-up to measure the bit error rate (BER) of the system is given in Fig. 4.5.

The error detector detects error in an incoming maximal-length sequence. A 7-bit PN sequence (matched to the sequence generated in the error detector) was applied to

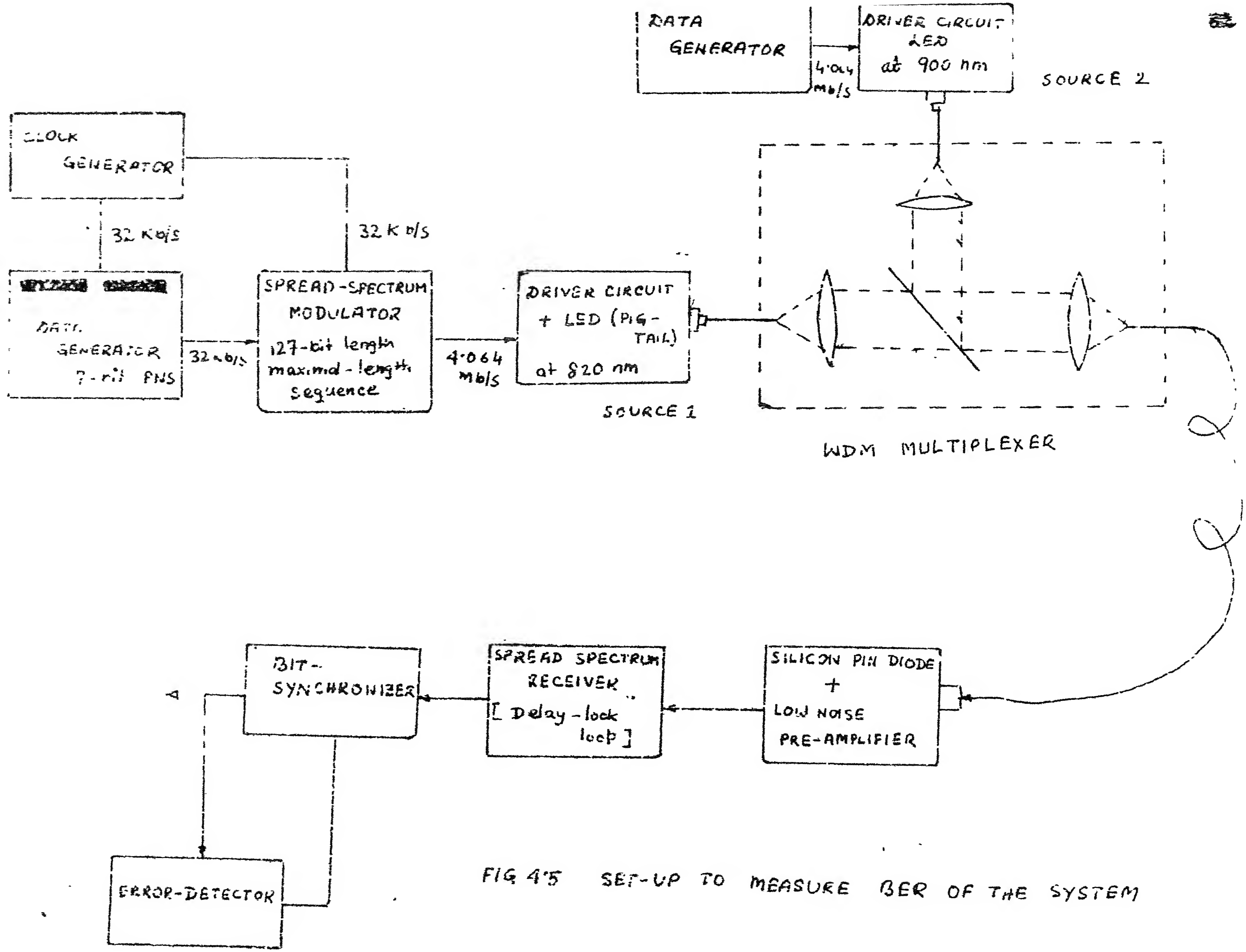


FIG 4.5 SET-UP TO MEASURE BER OF THE SYSTEM

to the spread-spectrum modulator. At the receiver end, BER of the recovered signal was measured with and without the presence of the second channel which acts as an interfering source to channel 1. Measured values of BER are given ~~below.~~ in sec. 4.4

4.3.3 Now the entire system as given in Fig. 4.1 was connected. Frequency of the input sine-wave was varied over the entire speech spectrum. (300 Hz to 3.5 KHz). The output obtained was a stair-case approximation of the input analog signal. The output can be made smooth if it is passed through a low-pass filter. In absence of the second channel the receiver circuit faithfully reproduces the signal, but in the presence of that channel, the recovered signal quality shows some degradation in the form of abrupt dips and peaks in some parts of the signal. Measured values are given below.

Max. possible input amplitude at 300 Hz = 1.1 Volts

Max. possible input amplitude at 3.5 KHz= 75 mV

Readings were taken just before the slope over-load condition.

These readings, however, remain the same when the second channel is also operating.

4.4 RESULTS:

DIFFERENT PARAMETERS MEASURED

1. The following parameters have been measured for the WDM scheme implemented.

a) Maximum operating frequency of source 1 (= 820 nm) = 15 Mb/s

Maximum operating frequency of source 2 (= 900 nm) = 9 Mb/s

b) Output of receiver pre-amplifier when only source 1 is operating : 25 mV.

Output when only source 2 is operating : 17 mV

Output when both are operating : 42 mV

2. Different Bit Errors of the System are shown below.

Bit Error Rate of the data coming from source 1

a) With source 2 off : no error detected during 15 min. of observation.

b) With source 2 on : 1.0×10^{-7}

CHAPTER 5

CIRCUIT DESCRIPTION OF THE SUB-SYSTEMS USED IN THE LINK

In this chapter some of the circuits used at different points in the system have been described and their circuit - diagrams have also been provided. These circuits include LED driver, low-noise receiver pre-amplifier, adaptive delta modulation (ADM) transmitter, bit-synchronizer and ADM receiver. Algorithms and principle of operation of these circuits have been given wherever necessary. LED driver circuit and receiver pre-amplifier are integral parts of any fiber-optic communication system. They have been designed and fabricated to operate above 10 Mb/s. It was intended to send a spread - spectrum modulated speech signal through the channel. The ADM transmitter has been used as source coder which digitizes the speech signal. It has 16 different step-sizes and operates with 32 Kb/s clock. At the receiver end bit synchronizer circuit using modified digital phase-lock-loop was fabricated to extract the clock of the delta modulated speech signal. Finally ADM receiver which is essentially same as the local decoder circuit in the ADM transmitter has been described.

5.1 LED DRIVER CIRCUIT:

LED's are current driven directly modulated light

sources. Figure 5.1 shows the LED driver circuit. The LED that has been used emits at a wavelength of 820 nm and has a wave-length spread of 35 nm. Other specifications of LED have been given in the Appendix.

This circuit is relatively straight-forward. Basically it is a switching circuit capable of driving current from zero to 250 mA at high speed (excess of 15 Mb/s). It operates from a single +5V supply. The principle of operation of this circuit is same as that employed in a standard TTL gate. Q_1 and Q_2 have been used to hasten the drain of stored base charges from Q_3 and Q_4. The resistor connected in séries with the LED can be varied to set the LED driving current at a particular value. Incorporation of a line-driver reduces the loading of the input, if there is any. The capacitor C smoothes out the huge power supply transient spikes which affect the operation of the circuit. Two similar stages have been connected in parallel to increase the current driving capability without affecting the speed of operation.

5.2 LOW-NOISE RECEIVER PRE-AMPLIFIER [17,18]:

A BJT input receiver pre-amplifier has been designed and fabricated. It operates at frequencies in excess of 10 Mb/s. At such high frequencies the input impedance of FET shows a drastic fall which reduces the gain of the amplifier

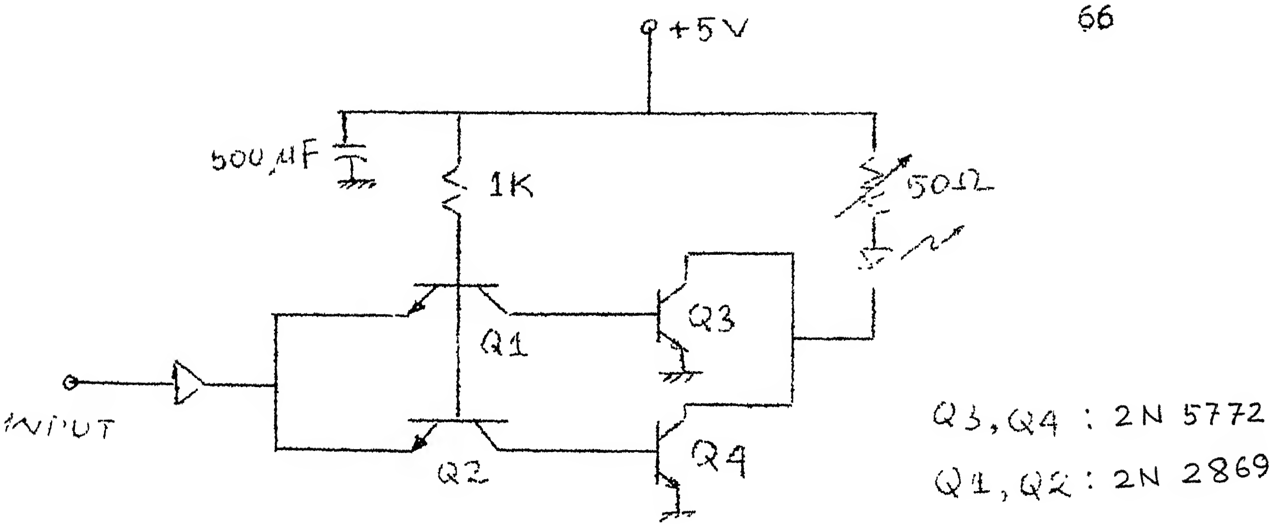


FIG 5.1 LED DRIVER CIRCUIT

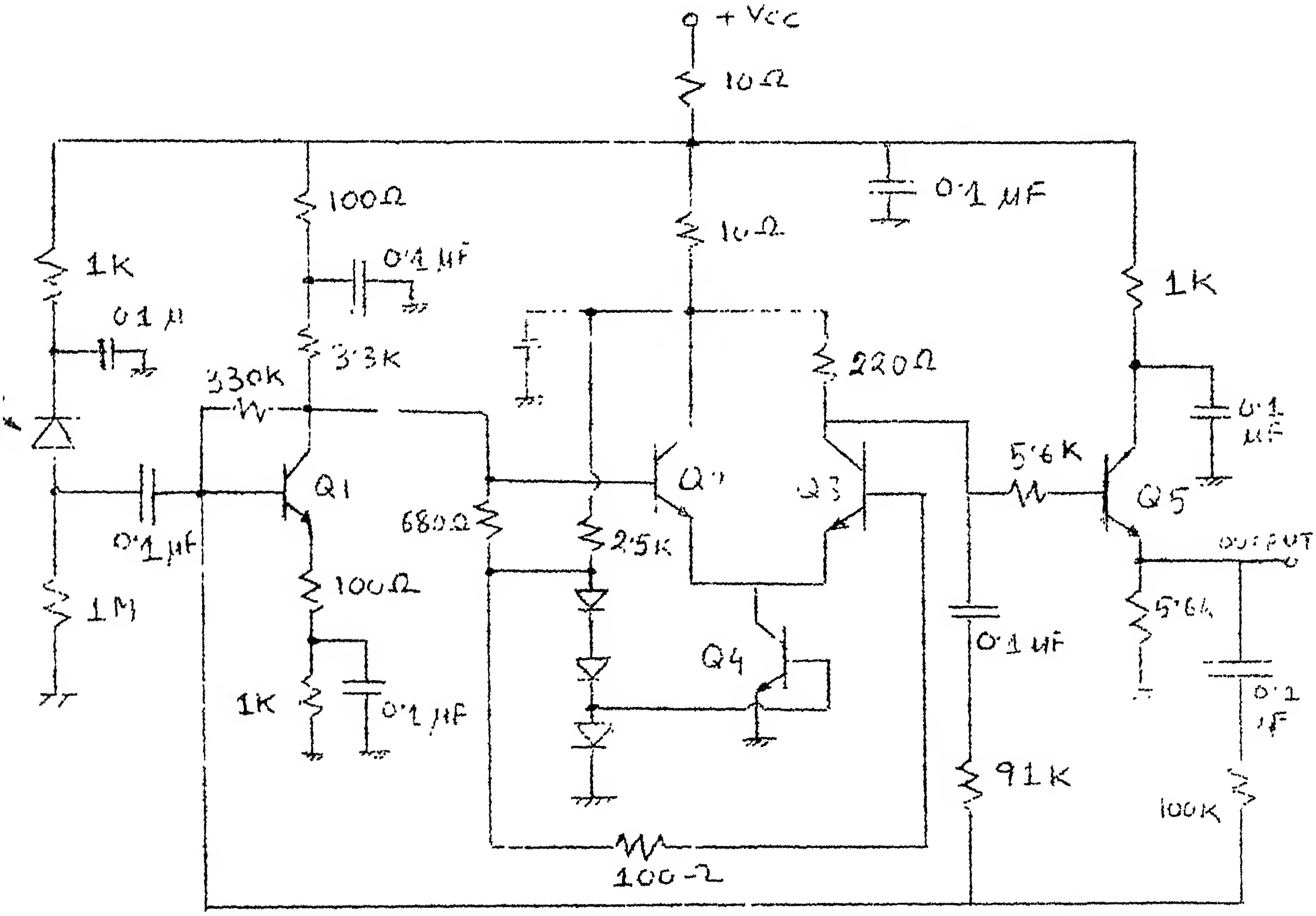


FIG 5·2 RECEIVER PRE-AMPLIFIER

and increases its noise-figure. One of the transistors of ultra-high speed transistor array (CA 3127, $f_T > 1$ GHz) has been used to keep the characteristic unchanged throughout its operating range. The detailed circuit diagram is given in Figure 5.2. Transimpedance type feedback has been applied to avoid the use of an equalizer at such high data rates. The receiver circuit has been built-up in three stages. First stage provides high input impedance to the signal coming out of the PIN photo diode. This also improves the noise figure of the amplifier[7]. The intermediate stage is a cascode amplifier stage. The output of the first high input impedance stage has been designed to match the cascode amplifier stage. Incorporation of cascode stage reduces the effect of Miller capacitance which can significantly affect the performance of the receiver circuit specially at high frequencies. The final stage is an emitter follower to enhance the driving capability. Feedback has been applied in two stages, from the cascode amplifier stage and the emitter follower stage. Potential divider arrangement for the biasing of the final emitter follower stage has been avoided to increase into input impedance. Biasing d.c. current, however, is being supplied by the stage before it. No a.c. coupling has been done between these two stages for that reason. A few readings have been taken to evaluate the performance of the receiver

circuit and they are listed in ~~the Appendix.~~ sec 5.6. These results include the rise time, fall time, gain vs. frequency, eye diagram at its maximum operating frequency etc.

5.3 LINEAR DELTA MODULATION:

In any delta modulation the digital version of the error signal is sent into the channel. In case of linear delta modulation, if the receiver receives '1' it interprets it as a command to increase the signal amplitude by a predetermined amount whereas it decreases the signal amplitude by the same amount upon receiving a '0'. This increment or decrement value of the signal level is a fixed quantity. To send the correct error information, a local decoder circuit is built in the transmitter to construct the signal from the data pattern sent by the transmitter. The incoming signal is constantly compared with the local decoder output, decision so as to send a one or zero is taken accordingly and transmitted at a rate determined by the clock supplied externally. The receiver circuit is an integrator whose time constant determines the step size and it is usually kept the same as the transmitter step-size to reproduce the signal faithfully.

In stead of using analog integrator, it is possible to

construct the local decoder circuit and the receiver by using mode control up/down counters and digital to analog converter (DAC). The circuit was constructed according to the flowchart given in Fig. 5.3.

The mode control pin of the counter 74191 is connected directly to the input so that if the received data is '1', the counter counts up and it counts down if the input is zero. The ripple carry output has been used to indicate overflow or underflow and it is directly connected to the counter inhibit pin. Two four-bit counters were used and the final stage ripple carry output was used to indicate overflow/underflow. Ripple carry of first stage, however, was used for cascading. The eight output pins of the two 4-bit counters are connected to DAC 0808 which gives the equivalent analog output. ~~Circuit diagram has been provided in the Appendix.~~

With this local decoder, the linear delta-modulation transmitter stands as shown in Figure 5.4.

5.4 ADAPTIVE DELTA MODULATION (ADM):

In adaptive delta modulation, the step-size is not constant, but becomes a function of the instantaneous slope of the input signal. Step-size is progressively increased under slope overload situation. Slope overload is detected

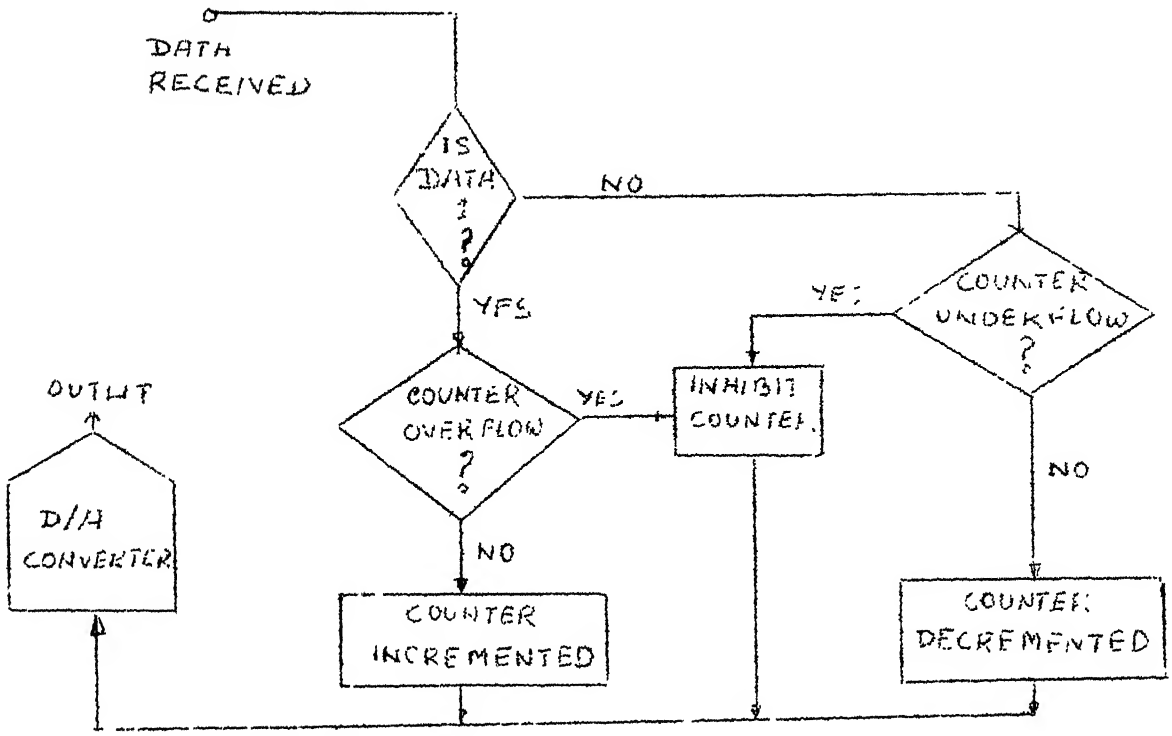


FIG 5.3 OPERATIONAL FLOW CHART FOR LINEAR DELTA MODULATION LOCAL DECODER AND RECEIVER

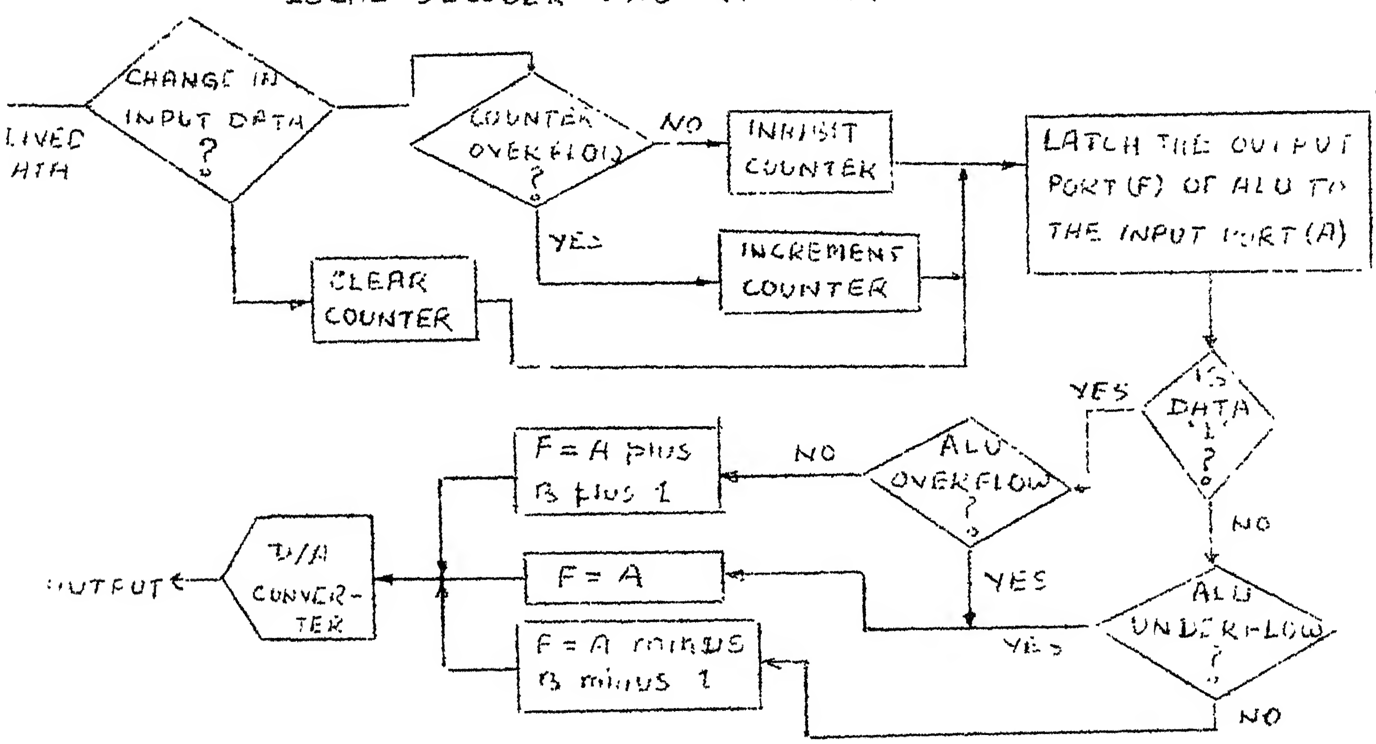


FIG 5.5 OPERATIONAL FLOWCHART FOR ADAPTIVE DELTA MODULATION LOCAL DECODER AND RECEIVER

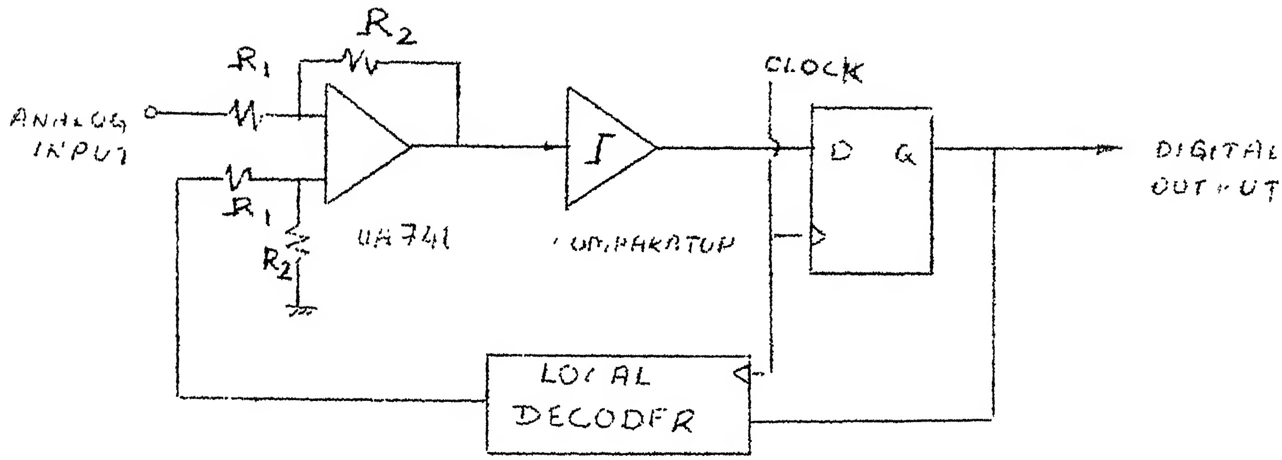


FIG 5.4 DELTA MODULATION TRANSMITTER

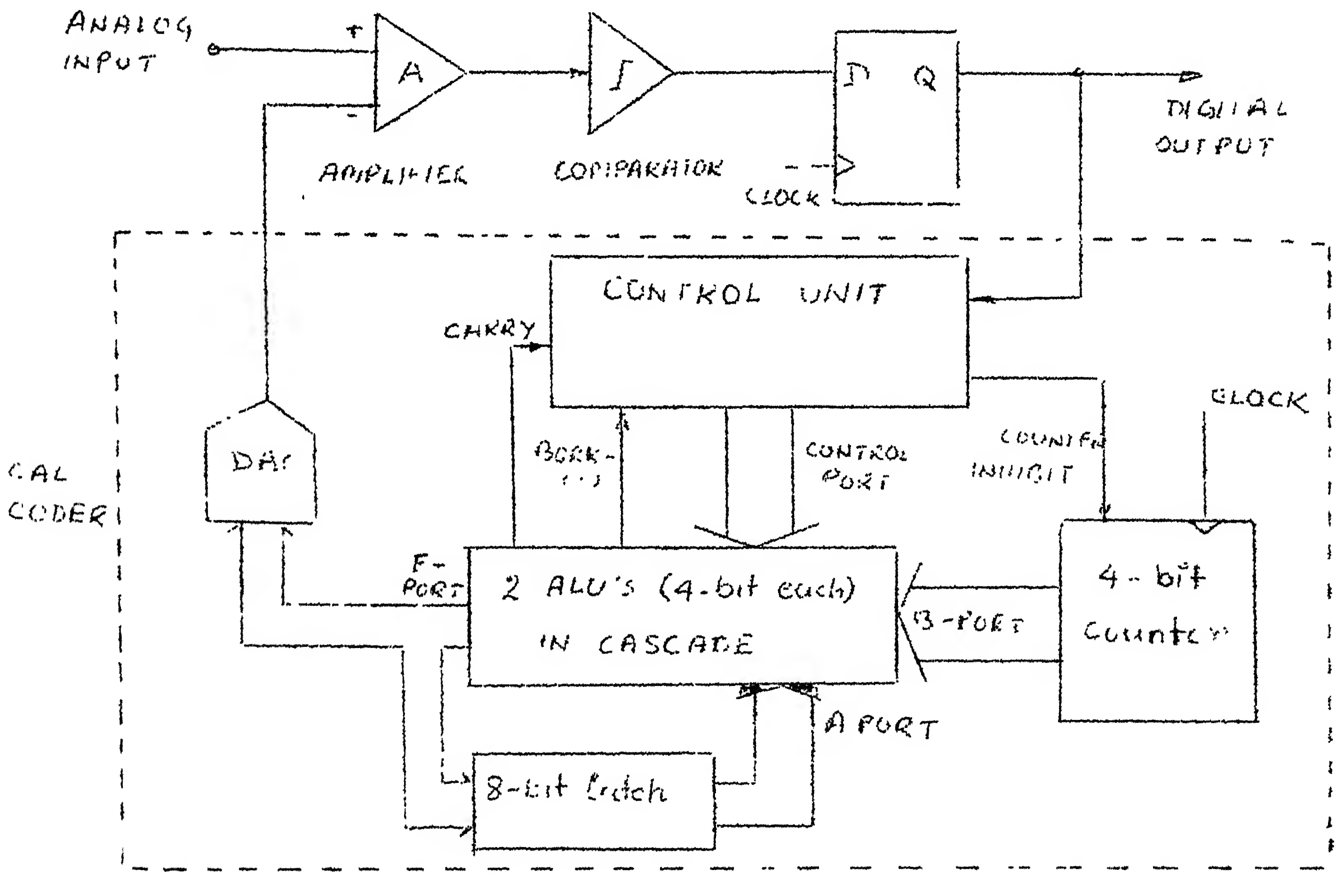


FIG 5.6 BLOCK SCHEMATIC FOR ADAPTIVE DELTA MODULATION TRANSMITTER

by the presence of successive one's or zero's in the transmitted data stream. In the present case occurence of two 1's or 0's have been considered for this purpose.

In the present circuit an adaptive digital integrator has been made using 4 bit counter and an ALU unit which can accommodate 16 different step sizes. The sequence of operations in the local decoder circuit and the receiver circuit has been given in the flow-chart as shown in Figure 5.5.

ALU's have 5 control pins, the states of these pins determine the algebraic or logical function it carries out on the two sets of inputs, each having 4 bits. In both the stages of ALU A_0, A_1, A_2, A_3 (A port) are connected with outputs F_0, F_1, F_2, F_3 (F port) through +ve edge triggered latches. Other input lines B_0, B_1, B_2, B_3 (B port) are connected directly to the outputs of a 4 bit counter. Same clock is connected to the buffer, counter and D flip-flop. In block schematic the entire transmitter stands as shown in Figure 5.6.

Each ALU chip (74181) has separate leads to indicate carry and borrow overflows. These leads were used to cascade two stages. Two complementary timer circuits have been used to generate pulses at each data transition and thereby clear

the counter. The counter unit instructs the ALU's to perform 'A plus B^1' where B^1 is the B-port of 1st ALU stage only whenever the data is high. Since the output port F is connected to A-port through latches, at each clock, contents of F-port appear at A-port and the total count of ALU goes on increasing on receiving successive ones. The increment of step-size is accomplished by the counter whose outputs are connected to B^1-port and which keeps on counting so long as there is no change of data. If data does not change even after 15 clock periods, counter operation is inhibited and it retains its value at 15. Thereafter it maintains a fixed step-size for further appearance of same data.

The function of the control unit is determined by the following tables.

First Stage of ALU $\qquad$ M = Low

Data	Control Outputs S_0	S_1	S_2	S_3	C_n	Operation: F=	Overflow/ underflow
L	L	H	H	L	H	A minus B minus 1	$G \rightarrow H$
L	L	H	H	L	H	A minus B minus 1	$G \rightarrow L$
H	H	L	L	H	L	A plus B plus 1	$C_{n+4} \rightarrow H$
H	H	L	L	H	L	A plus B plus 1	$C_{n+4} \rightarrow L$

Table 5.1

Overflow of ALU is indicated by a low at C_{n+4} pin and it has to be sampled while data is high. Correspondingly, underflow is indicated by a low at G pin which is sampled when data is low.

The functions of the control circuit for the 2nd stage of ALU is tabulated below:

X indicates 'don't care' states

Table 5.2

Second Stage of ALU M = Low

Input to Control Stage			Control Outputs of 2nd ALU					Operation
Data	G from 1st ALU	C_{n+4} from 1st ALU	S_0	S_1	S_2	S_3	C_n	
L	L	X	H	H	H	H	H	F = A minus 1
L	H	X	L	L	L	L	H	F = A
H	X	L	L	L	L	L	L	F = A plus 1
H	X	H	L	L	L	L	H	F A

With these operations the step-size increase algorithm becomes as follows:

Initial conditions : Counter content = 0

ALU outputs = 0

Data = Low

Table 5.3: Step-size Algorithm

Clock No.	Data Received	Counter Content	ALU outputs
1	H	0	1
2	H	1	3
3	H	2	6
4	H	3	10
5	H	4	15
⋮	⋮	⋮	⋮
12	H	11	66
13	H	12	78
14	H	13	91
15	H	14	105
16	H	15	120
17	L	0	119
18	L	1	117
19	L	2	114

8 output pins (F-port), four from each stage of ALU, are connected to the 8 inputs of DAC 0808. It gives the corresponding analog output.

The error signal thus constructed in the local decoder circuit is compared with the original incoming signal and rest of the processing is same as that described in Section 5.3. In the transmitter, overflow or underflow prevention circuit is not necessary because the error signal is being continuously compared with the original signal. This consideration is important in the receiver circuit where there is no reference input signal. The detailed circuit diagram is provided in Figure 5.11.

5.5 ADAPTIVE DELTA-MODULATION RECEIVER CIRCUIT:

Essentially the receiver circuit is the same as the feedback path circuit which is the local decoder at the transmitting end. Therefore it requires the data clock for its operation. A 'delay-and-multiply' synchronizer circuit has been made to extract clock from the data. This circuit is described below.

5.5.1 Delay and Multiply Bit Synchronizer [19]:

The block schematic of the synchronizer is as shown in Figure 5.7.

For digital signals multiplication operation can be accomplished by exclusive-OR. The narrow bandpass filter has been realized by modified digital phase lock

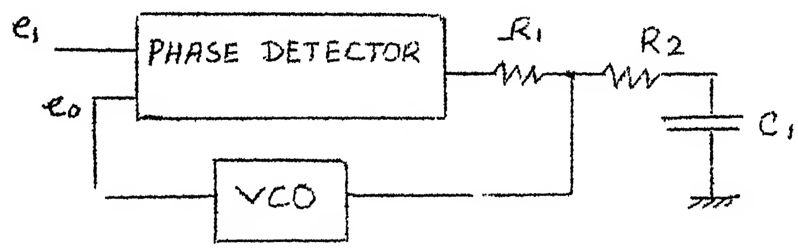
loop[20] (PLL). The delay of approximately half of the clock was obtained by two monostables and an inverter. The PLL used here acts as a band-pass filter whose pull-in range and lock range should be selected depending on the data rate.

Theoretically it is desirable to have a large pull-in range, wide capture range and very narrow band-width. But these three parameters cannot be chosen independently specifically when stability is also considered[21]. For a first-order loop, expressions for damping factor and natural frequency become

$$\omega_n = \left[\frac{K_O K_D}{R_1 C_1} \right]^{1/2} \qquad K_O K_D \quad \text{loop gain}$$

$$\xi = \left[\frac{1}{2(R_1 C_1 K_O K_D)} \right]^{1/2}$$

From the above expressions it can be seen that large time constant for R_1C_1 or high loop-gain (K_OK_D) will reduce the damping factor and hence decrease stability. Therefore, if a narrow band-width is desired, the damping factor will become very small and instability will result. It is not possible to adjust bandwidth, damping factor and loop gain independently. To avoid this following loop filter configuration has been used (Fig. 5.8).



$\tau_1 = R_1C_1$

$\tau_2 = R_2C_1$

Fig. 5.8: PLL with 2nd order loop filter

In this case the four design formulas become:

$$\omega_n = \left[\frac{K_O K_D}{1 + 2} \right]^{1/2}$$

$$\delta = \frac{\omega_n \tau_2}{2}$$

Pull-in range $\omega_p = \pm \sqrt{2}\,(2\xi\omega_n K_O K_D - \omega_n{}^2)^{1/2}$

Hold-in range $\omega_H = \pm K_O K_D$

We choose = 0.1 and ω_n = 32 Kb/s. Values of R_1, R_2 and C_1 found by iteration are

$$R_1 = 10K$$
$$R_2 = 1.5K$$
$$C_1 = 0.1\,\mu F$$

For these values $\Delta\omega_H$ = 1 Kb/s and $\Delta\omega_p$ = 5 Kb/s

The total bit synchronizer circuit, therefore stands as shown in Figure 5.9.

5.5.2 Signal Construction

Rest of the receiver circuit is same as the local decoder circuit of the transmitter with a provision to hold the states of 8 input lines of DAC 08C8 whenever the second-stage of the ALU shows a overflow. To indicate underflow from second ALU stage a separate circuit has been made, because G pin of74181 gives false indication of underflow for control input pattern

$$S_0 = S_1 = S_2 = S_3 = C_n = H$$

and

$$S_0 = S_1 = S_2 = S_3 = L \text{ and } C_n = L$$

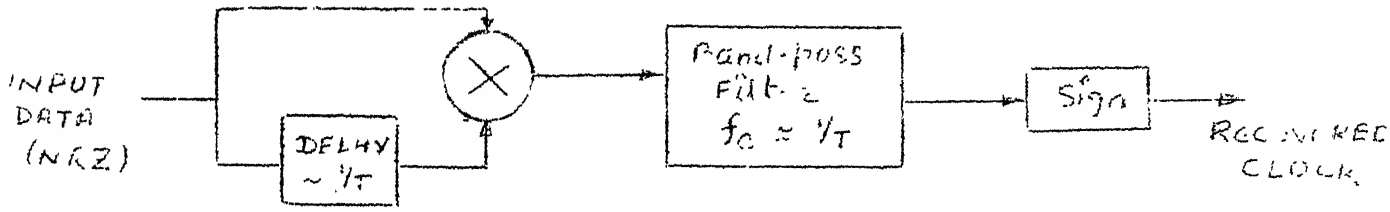


FIG 5.7: BLOCK DIAGRAM FOR DELAY AND MULTIPLY SYNCHRONIZER

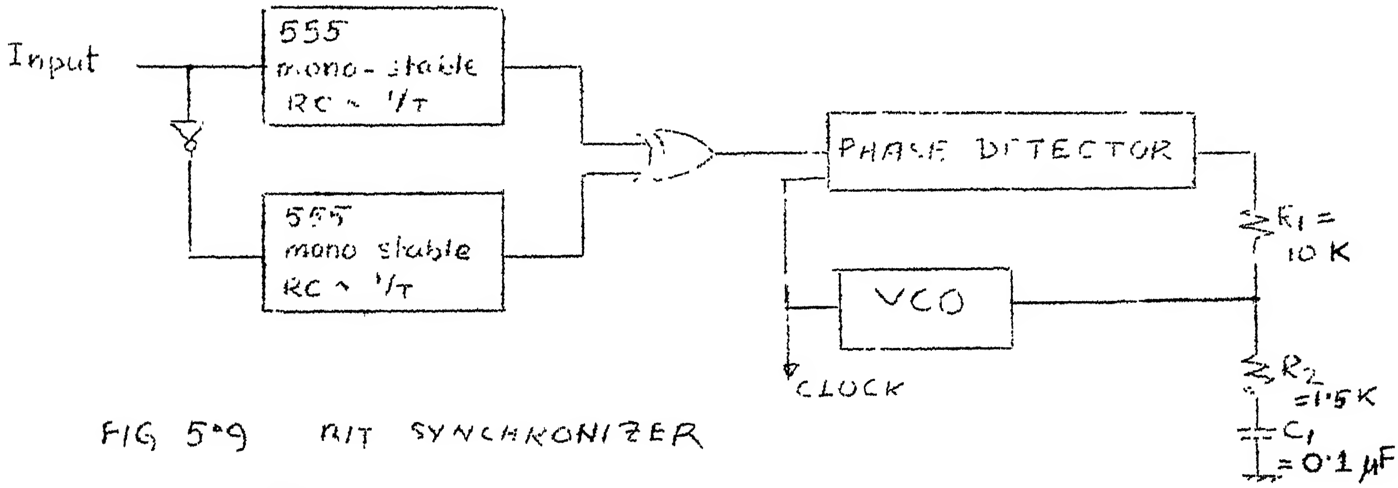


FIG 5·9 BIT SYNCHRONIZER

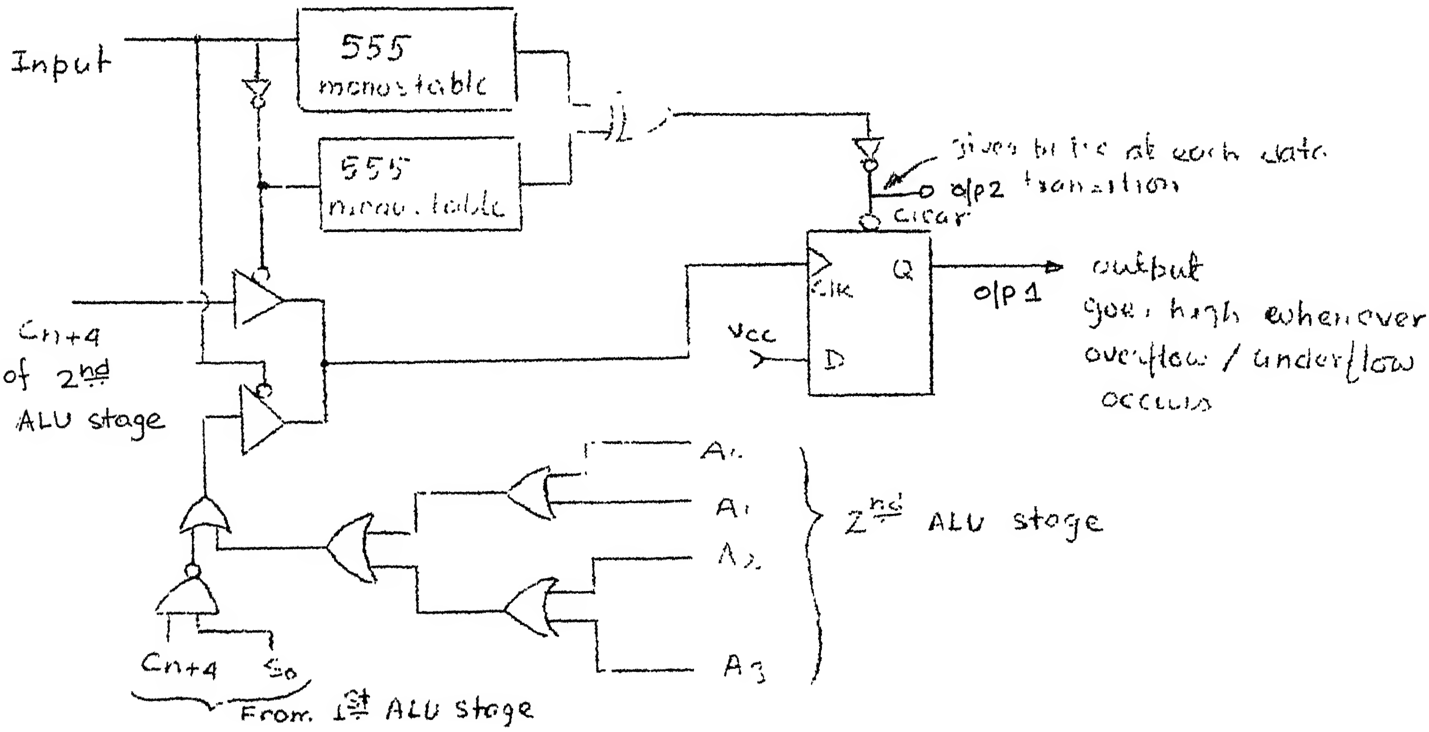
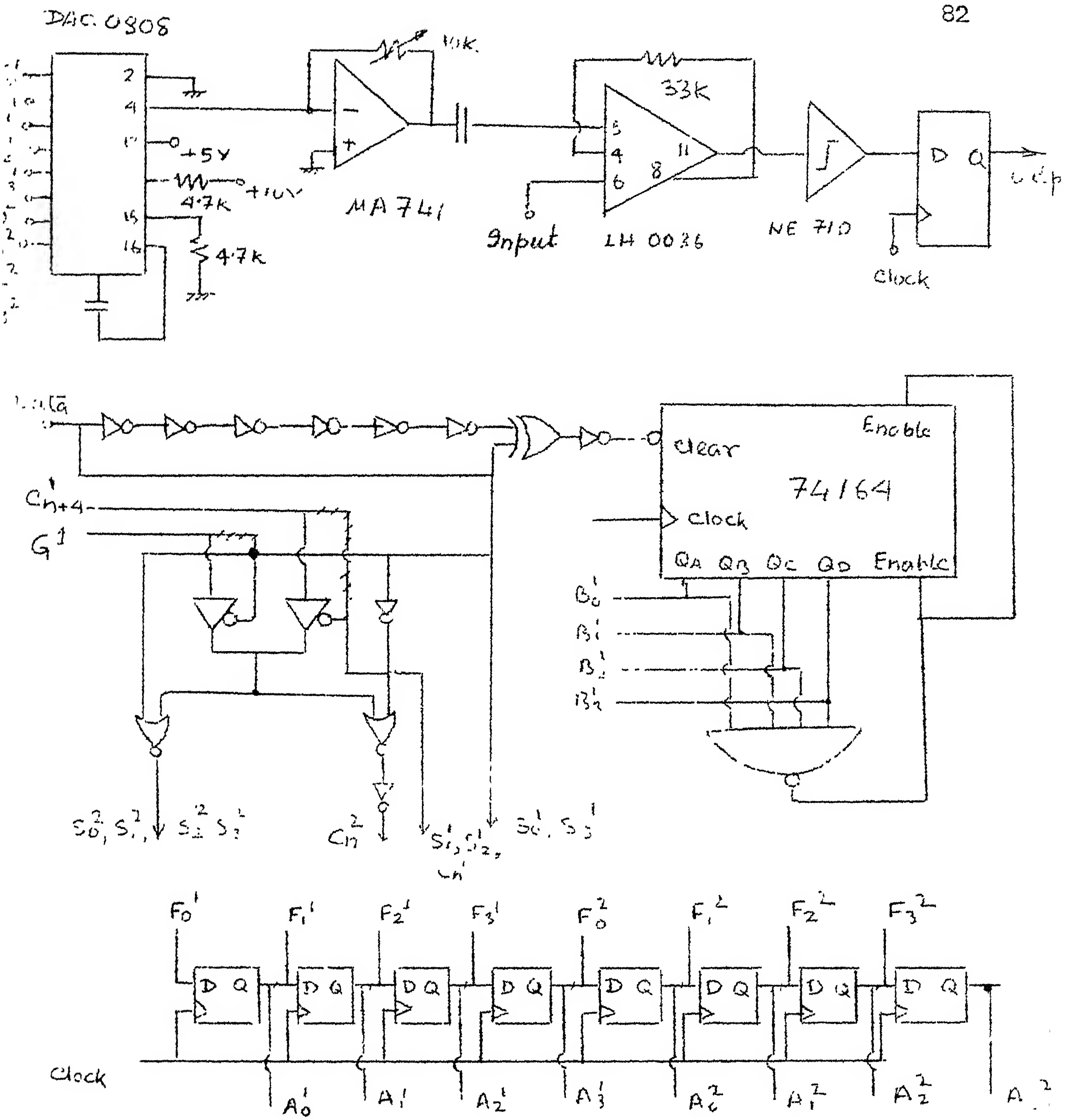


FIG 5.10 OVERFLOW / UNDERFLOW INDICATOR

C_{n+4}, however, gives correct overflow indication for all conditions.

The circuit used to check this overflow and underflow is shown in Fig. 5.10. Whenever overflow or underflow occurs output Q of D flip-flop goes high and it inhibits the arithmatic operation of ALU and forces it be ~~to~~ in the 'hold on' mode i.e. F → A. This condition persists so long as there is no change in data. Whenever data changes its state a pulse is generated which clears the flip-flop and the normal arithmatic operation starts again. This has been realized by using a few more logic gates in the control unit (OR and NOR). The gain of the circuit can be set by changing the resistor which provides trans-impedance feedback in the current to voltage converter (using 741) connected at the output of DAC 0808. Detailed circuit diagram is given in Figure 5.12.

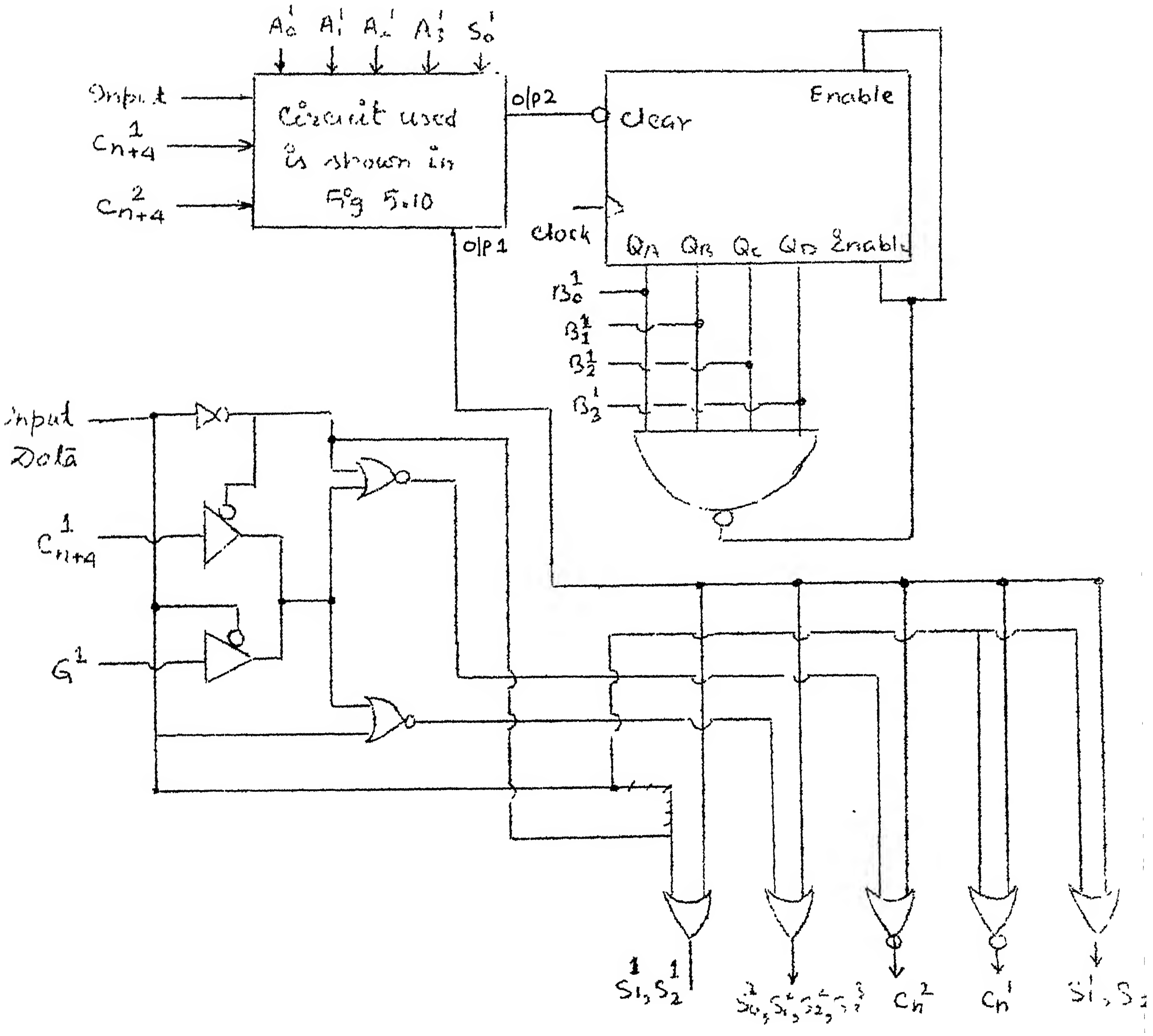


ALU used : 74181

A_0^1 → to be connected to pin A_0 of 1st ALU,

A_0^2 → " " " " pin A_0 of 2nd ALU, etc

FIG 5.11 : ADM Transmitter circuit Diagram



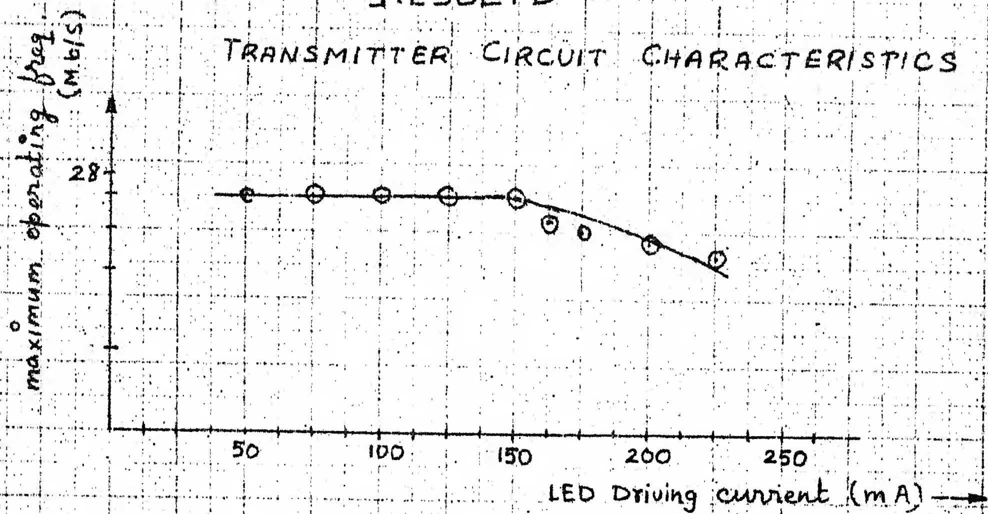
~~AB~~ ALU, DAC and Latch used are same as shown in Fig 5.11.

$A_0^1 \longrightarrow$ to be connected to 1st stage of ALU, etc.

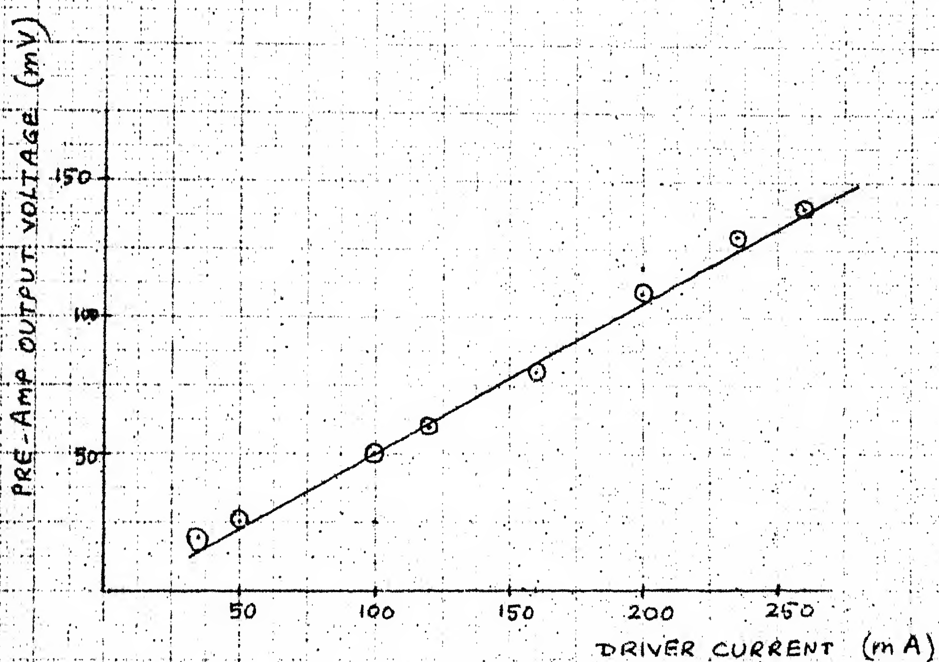
FIG 5.12 : ADM Receiver circuit diagram

5.6 : RESULTS

TRANSMITTER CIRCUIT CHARACTERISTICS

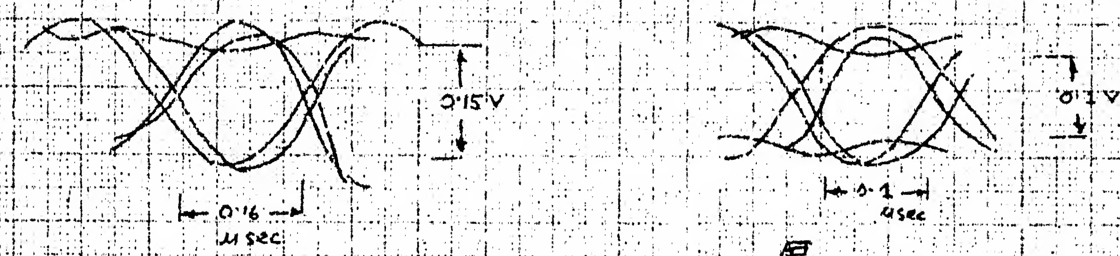


DRIVER CURRENT Vs. MAX. OPERATING FREQ.



DRIVER CURRENT Vs. PRE-AMP OUTPUT VOLTAGE

RECEIVER PRE-AMPLIFIER EYE-DIAGRAM
(ROUGH SKETCH)

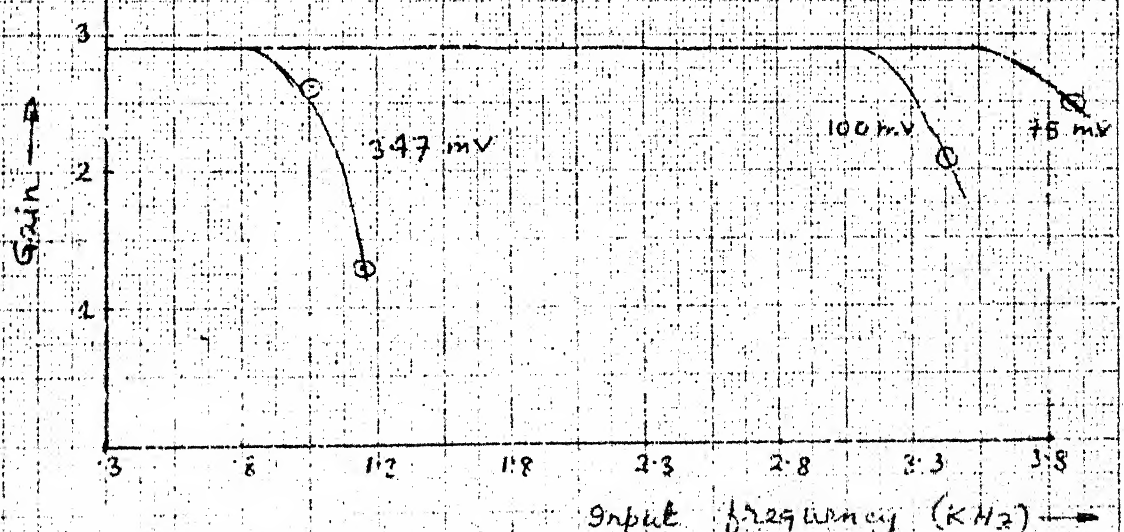


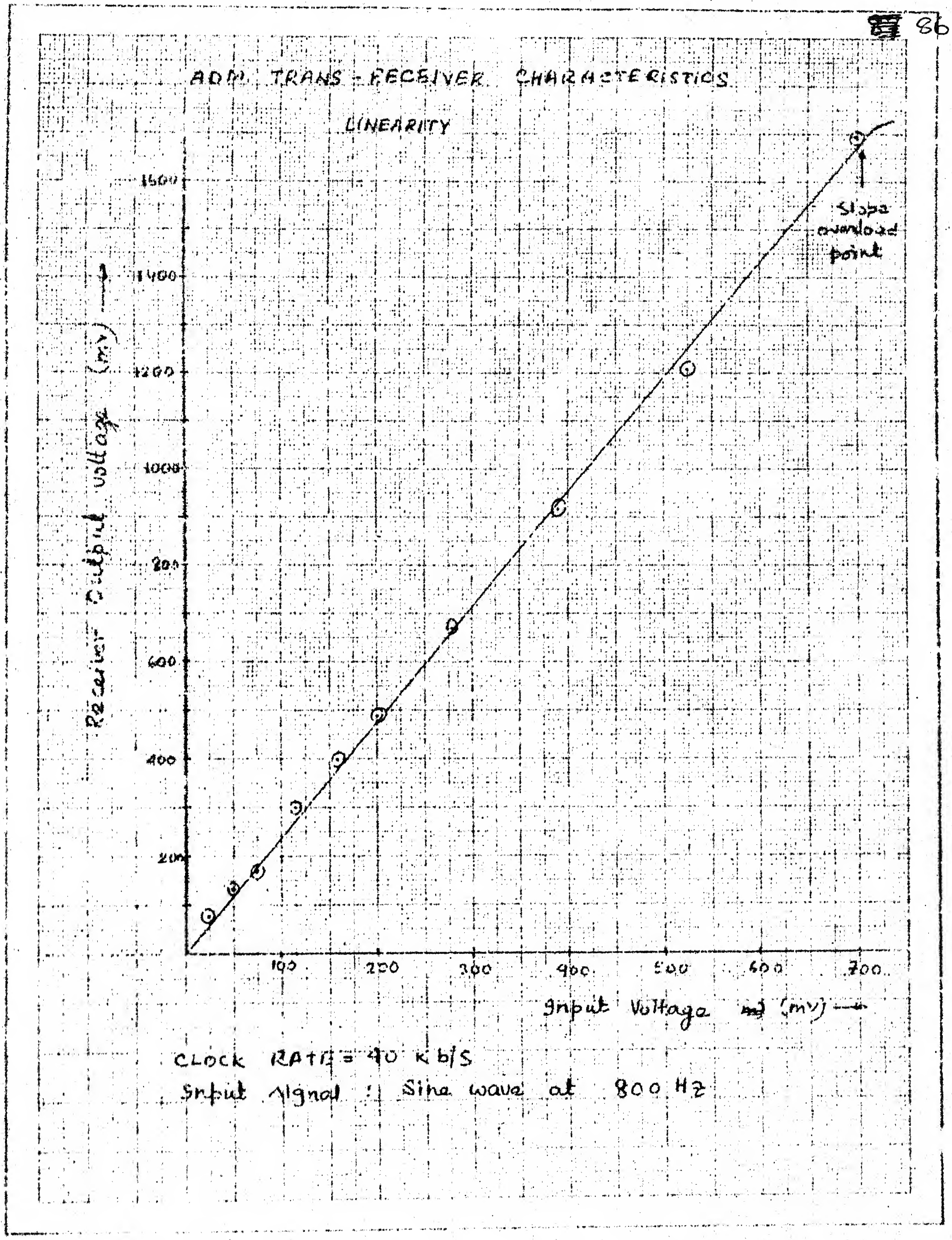
AT 6·3 M b/s

AT 11 M b/s

ADM TRANS - RECEIVER CHARACTERISTICS

CLOCK RATE 40 Kb/s : Input Applied → Sine Wave
parameter → Signal amplitude



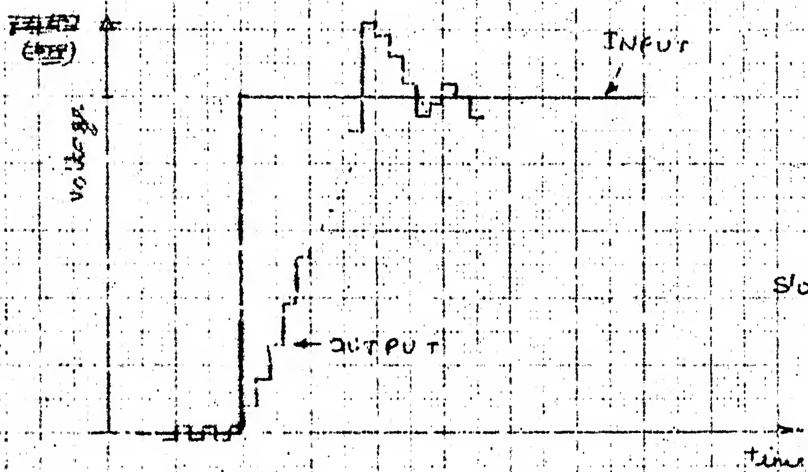

ADM TRANS - RECEIVER CHARACTERISTICS
LINEARITY
1600
1400
1200
1000
800
600
400
200
Receiver Output voltage (mV)
100
200
300
400
500
600
700
Input Voltage (mV)
Slope overload point
CLOCK RATE = 40 K b/S
Input signal : Sine wave at 800 Hz

ADM TRANS - RECEIVER CHARACTERISTICS

TRANSIENT RESPONSE

CLOCK RATE : 40 Kb/s

INPUT APPLIED : Step



Slope = 1·225 V/40·83 μs

= 30 mV / μs

OUTPUT WAVE-FORM FOR STEP-INPUT

(a) For 1·436 mV step amplitude

No. of steps required = 7

Max. step size = 115·7 mV

Min. step size = 14 mV

Overshoot = 53·6 mV

(b) For 525 mV step amplitude

No. of steps required = 13

Max step size = 98·6 mV

Min step size = 14 mV

Overshoot = 53·71 mV

Receiver Pre-amplifier Frequency Response:

1. Transmitter power kept fixed.

PIN diode output	Pre-amp. output	Frequency	Gain
.006V	.15V	200 Hz	25
"	.14V	500 Hz	23·3
"	.13V	1 KHz	21·7
"	.12V	2 KHz	~~25~~ 22
.005V	.12V	5 KHz	24
.004V	.12V	10 KHz	30
.003V	.11V	20 KHz	36
.001V	.11V	50 KHz	110
Unidentifiable	"	100 KHz	
	"	200 KHz	
	"	500 KHz	
	"	1 MHz	
	"	2 MHz	
	"	5 MHz	
	"	9 MHz	
	"	11 MHz	

Receiver rise-time 0.09V/.05 μsec

Fall-time 0.09V/0.07 μsec

CHAPTER 6

CONCLUSION

6.1 PERFORMANCE OF THE OVERALL SYSTEM AND SUBSYSTEMS:

A data link has been implemented combining wavelength division multiplexing and spread spectrum modulating techniques. SSM technique allows the users to access the channel asynchronously without using any protocol whereas WDM multiplexer provides a simple but efficient node configuration at some intermediate points in the channel. Performance of the system can be evaluated on the basis of the measured values of the following factors.

a) Multiple Access Capability

b) System BER with number of users

c) Maximum operating frequency

d) Performance as voice data link

e) Economy of the system

f) Loss consideration

In the following, different measured values have been mentioned and compared, wherever possible, with theoretical values or data from similar system.

(a) and (b) : In the present system two asynchronous users have been used and they can access the channel simultaneously. In the following table the BER of the present system has been

compared with the theoretical values. Comparison of the values with some other practical systems was not possible for want of sufficient data.

Table 6.1:

No. of users	Theoretical SNR	Theoretical BER	SSM Sub-system BER	Overall system BER
1	8.86	$< 10^{-10}$	No error detected during 15 min. of ops.	No error detected
2	7.57	$.6 \times 10^{-8}$	"	4×10^{-6}
3	6.77	$.8 \times 10^{-6}$	0.65×10^{-5}	-
4	6.21	0.13×10^{-4}	0.74×10^{-4}	-
5	5.8	0.72×10^{-4}	0.31×10^{-3}	-
6	5.4	0.23×10^{-3}	0.11×10^{-2}	-
7	5.07	0.68×10^{-3}	-	-
8	4.8	0.13×10^{-2}	-	-

(For asynchronous users)

Higher BER of the overall system with two asynchronous users is probably due to jitter in the recovered data.

The performance can be improved with some modifications in the SSM circuits as suggested in Sec. 6.2 (ii).

c) Maximum operating frequency of the system is determined by the slowest source. In our system operating frequencies

for source 1 (= 820 nm) = 15 Mb/s

for source 2 (= 900 nm) = 9 Mb/s

The system can operate at 9 Mb/s.

This value goes down as the number of users increases due to the loss suffered for the addition of each source.

It has been observed that each source when connected directly with a single optic fiber operates at 20 Mb/s. If the division of energy with beam-splitter in WDM Mux is equal they should operate at nearly same frequency (which would be less than 20 Mb/s). THere the difference in the values of the maximum operating frequency arises because the unequal reflectivity and transmission of the beam splitter used. Improvements are possible if efficient WDM technique is used as suggested in Sec. 2.1.

d) The system exhibits wide and linear dynamic range for voice signal: from 75 mV to 700 mV.

This has been achieved mainly due to the adaptive delta modulator circuit being used as source coder and decoder. This range is much grater than that can be achieved using linear delta modulation. Comparison has not been made since sufficient data could not be accumulated.

The adaptive delta modulator circuit has some minor problems which introduces some distortion in the reproduced signal at the receiver end. Possible rectification has been suggested in Sec. 6.2(ii).

e) Different power losses could not be measured since sufficiently sensitive optical power meter was not available.

f) Actual comparison between the cost of this system and that of other type could not be done due to non-availability of such data.

6.2 SUGGESTIONS FOR IMPROVEMENTS:

SSM system performs better if two separate maximal length sequences (m-sequences) are used for synchronization and modulation. It is evident from the following expressions of cross-correlation (considering the presence of carrier).

$$SNR \approx \frac{k-1}{3W} \quad \text{for two m-sequences}$$

$$SNR \approx \frac{1}{N} \quad \text{for two bit-shifted pattern of same m-sequence}$$

The transmitter circuit should be modified accordingly, as shown in Fig. 6.1, if two m-sequences are used. In this scheme the decoder circuit is important because the two sequences are required to maintain a predetermined phase

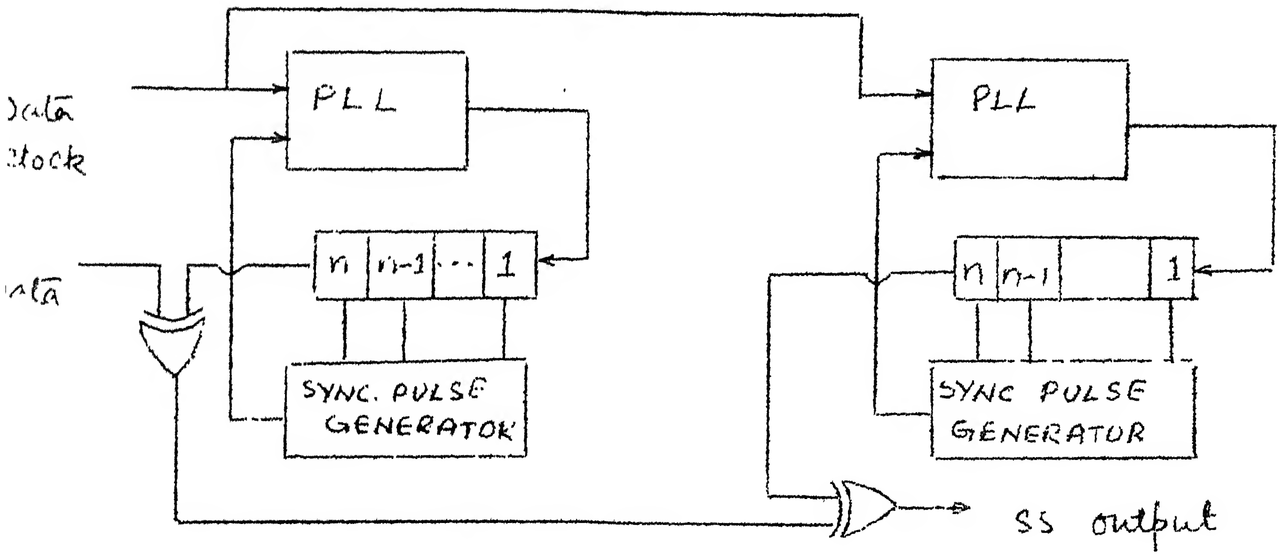


FIG 6.1 MODIFIED SSM TRANSMITTER

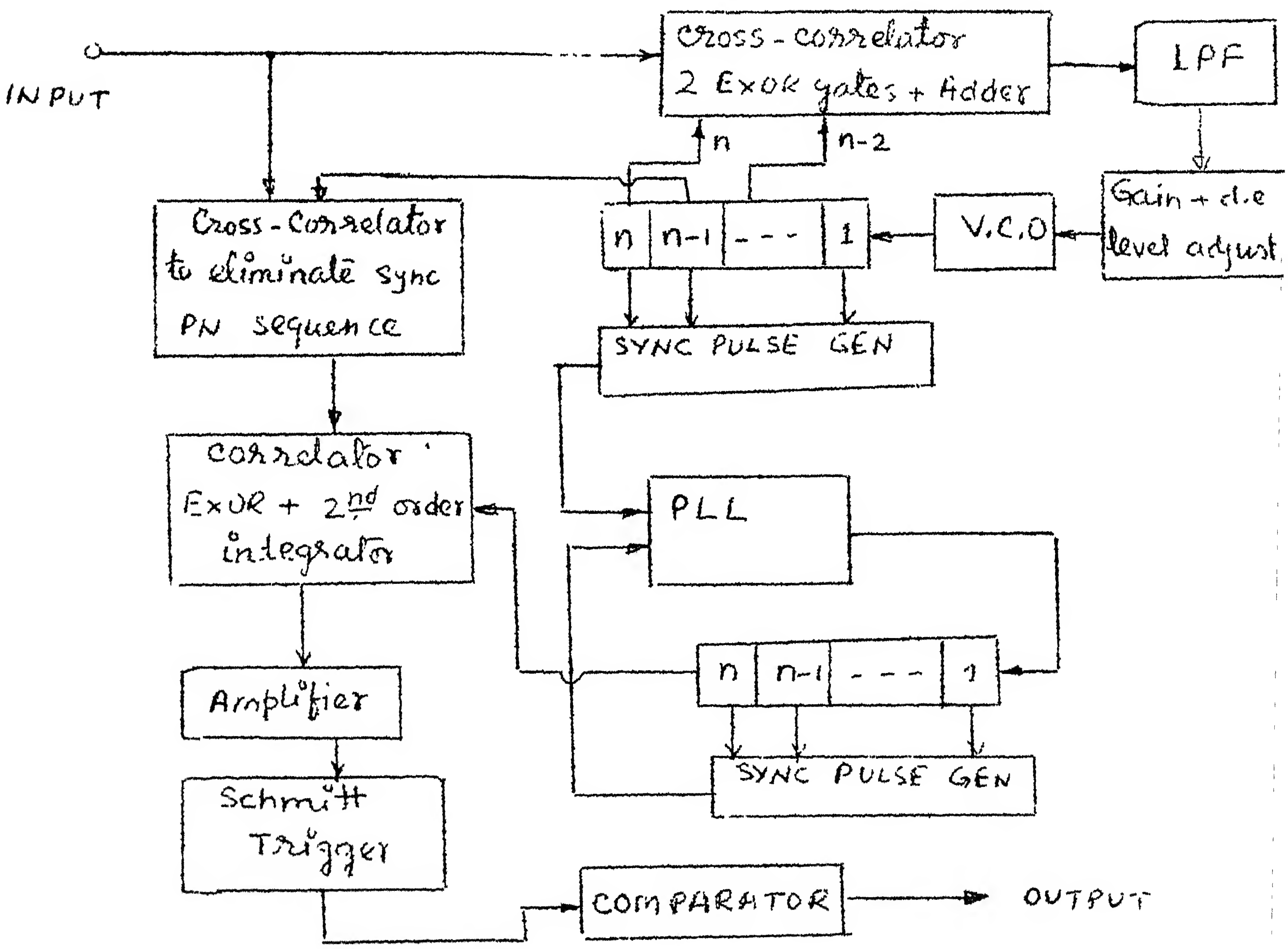


FIG 6.2 MODIFIED SSM RECEIVER

relationship. In the earlier scheme since two PN sequences are taken from different tappings of the same shift register, this relationship is automatically maintained.

The receiver circuit has also to be modified accordingly to acquire these two m-sequences in correct phase and frequency. For this purpose a PLL and decoder circuit will have to be used as shown in Fig. 6.2. The decoder should be identical to that used in the transmitter. The basic delay lock loop and data acquisition circuit however, remain the same.

ii) In the ADM transmitter it has been observed that the local decoder output shoots up at some random points and then gradually comes down in steps. This introduces distortion at the output of the receiver especially at low signal levels. This difficulty can probably be eliminated by introducing a overflow/underflow prevention arrangement in the transmitter. The basis for this comment lies in the fact that the receiver circuit where this feature has been incorporated, does not produce such random spikes.

6.3 APPLICATION:

i) Telemetry System: Where informations from different stations will have to be sent through a common channel to a monitor or control station, viz., power system telemetry.

ii) In a data network where data from different users located at different places can be entered or tapped from the channel.

iii) Using a demultiplexer, a duplex transmission system can be implemented using different wavelength sources

iv) Capacity of the system can be improved without a very significant modification of the hardware [using WDM multiplexer and demultiplexer].

6.4 SUGGESTIONS FOR FURTHER WORK:

In future to extend the capacity of the system works can be motivated in the following directions.

a) Design and fabrication of receiver pre-amplifier and LED driver at higher speed.

b) Use of more users in the channel and determination its limit.

c) Use of a WDM demultiplexer in the present system and evaluation of its performance.

d) Establishment of a full-duplex link and its performance evaluation.

APPENDIX

SPECIFICATIONS

a) Input Fiber:

Manufacturer : ITT, Type T-1221

Length used : 1 meter, Numerical Aperture (NA) = 0.22

Core diameter : SOP 51x50 μm^2 SOP = Start of file

EOP 51x52 μm^2 EOP = End of file

Outer diameter:

SOP : 124x123 μm^2

EOP : 124x126 μm^2

Dispersion 1.06 ns/km at the rate of 0.9 μm

Loss 6.1 dB/km at the rate of 0.85 μm

b) Output Fiber

Manufacturer : VALTEC , Type PCS

Core diameter = 250 μm

Clas diameter = 400 μm

Length used = 800 meters

Dispersion 40 ns/km, Numerical aperture = 0.3

c) Transmitter Module:

Manufacturer : ITT, Type TXC-05

LED type OFED-02C

High level output : 378 $\mu\omega$ = -4.23 dBm

Power supply current 271 mA

LED wavelength : 900 nm (center frequency)

d) PIN photo-diode:

Manufacturer : ITT, Type OFDP-04

Dark current : 0.248 nA (at -10V)

Response to 10 μω at -10V : 5.43 μA

Responsivity : 0.543 Amp/Watt.

e) Pigtailed LED source:

Manufacturer:Laser Diode Inc.,Type, IRE-150F

Termination pittailed 290/540 PCS fiber

Fiber core diameter : 290 μm

Numerical Aperture : 0.25

Center wavelength : 820 nm

Coupled power at fiber end : 67 μω

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